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FINAL REPORT

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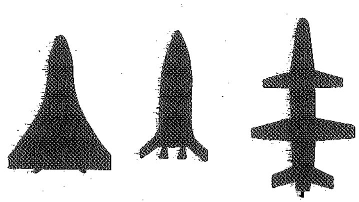
CONTRACT NAS 2-5022

Follow On Task Optimized Cost Performance Design Methodology



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FOREWORD

This report is submitted to NASA, the Mission Analysis Division of OART, as part of the final reporting on Contract NAS2-5022, Optimized Cost/Performance Design Methodology Follow-on Study. This five month study was initiated in November, 1969 and was performed in three general phases: a sizing and performance analysis, a definition of design data, and a parametric cost analysis. The Study Manager was L. M. McKay and the Deputy Study Manager was D. W. Haas. Other study personnel included B. Nelson, D. Chambers, G. Pease, V. E. Henderson, J. Nagy, A. D. Trautman, R. M. Calhoon, and R. Sanborn. The NASA Technical Monitor was C. D. Havill.

ABSTRACT

The two basic objectives of the study were to size zero stage strap-on rocket motors for a siamese booster/orbiter shuttle concept and derive parametric cost trends for two NASA shuttle concepts under current investigation, plus the siamese concept.

The approach to the study was to use specific vehicle weights and descriptions as input data to the cost model, developed under the basic OCPDM study and derive parametric cost trends for each vehicle as a function of variations in cargo per launch, total cargo requirements, launch rate variations, operational cost variations, and reusable versus expendable zero stages.

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SECTION 1.0 INTRODUCTION

The analysis of future missions and the evaluation of systems to perform missions requires continuous updating as mission definitions vary, as the candidate systems vary, and as improved evaluation techniques become available. Cost has always been included as one of the evaluation parameters and represents an area where increased emphasis on cost reductions has contributed to recently improved estimating techniques.

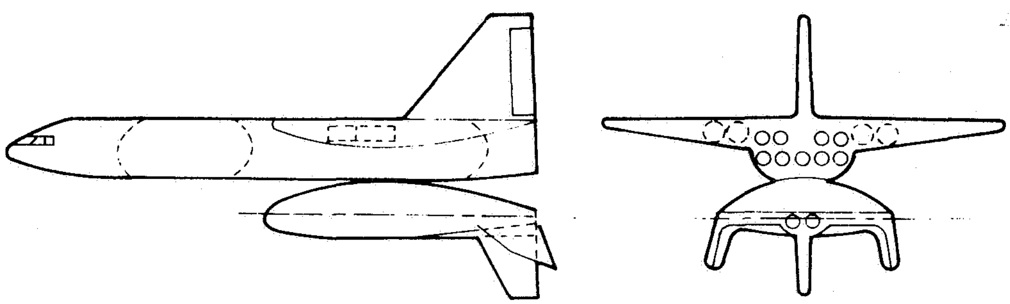
The basic Optimized Cost/Performance Design Methodology study, documented in McDonnell Douglas Report Number G975, dated 15 April 1969, provided a method of using cost as a basic design parameter in identifying and defining more economical space transportation systems. This study was performed in six tasks. Task 1 involved developing the cost data, organizing the data by categories, and developing cost estimating relationships. Task 2 and 3 developed the requirements and the physical and functional characteristics of the alternate spacecraft subsystems and operations. An analytical cost model was formulated in Task 4. Task 5 developed the logic, data and methods for systematically varying the design and operational specifications of each vehicle configuration. Using the data and tools developed in the other tasks, Task 6 determined the economically optimum design and operational philosophies; sensitivities to program size, launch rate, payload size; and the problem area and technology limitations.

The purpose of the current Optimized Cost/Performance Design Methodology Follow-on study was to exercise the cost model developed in the basic study for a family of future shuttle concepts as defined by the NASA. The primary objectives of the study were to (1) size zero stages (either solid or liquid pressure fed) and define desired velocity distributions for a siamese booster/orbiter concept and (2) derive parametric cost data for two shuttle concepts under current investigation, plus the siamese concept. The approach to the study was to use specific vehicle weights and descriptions as input data to the cost model and determine parametric cost trends for each vehicle as a function of variations in cargo per launch, total cargo requirements, launch rate variations, operational cost variations, and reusable versus expendable zero stages. Operational costs were derived on the basis of the work performed in the basic study and were also factored lower to show the effect of variations in these costs on the total program. The cost data used for the zero stages was provided by the NASA.

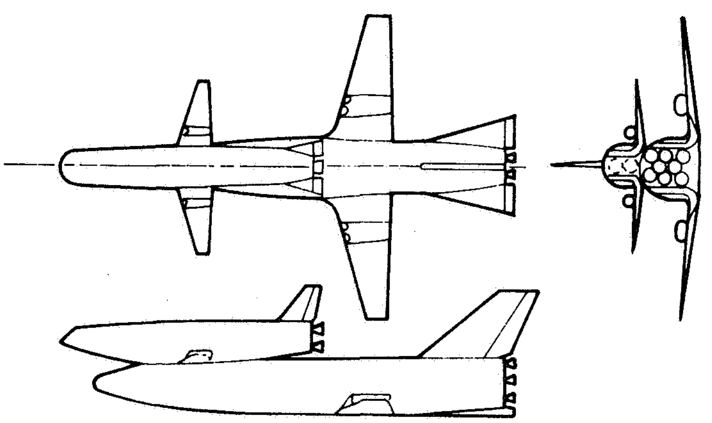
Two versions of a fully reusable two stage shuttle and a, two and one half stage shuttle concept were investigated as shown in Figure 1-1. The two stage configurations designated Concepts "L" and "M" represent recently completed studies performed for the NASA-LRC under Contract NAS9-9204 and for the NASA-MSC under Contract NAS9-9204 Schedule II, respectively. The basic core vehicles for Concept "S" was based on the use of the orbiter vehicle as defined in a recent study conducted by McDonnell Douglas for SAMSO/AFSC, under contract F047-01-69-C-0380. In Concept "S" both core vehicle's are identical. The additional ΔV required to achieve orbit is provided by zero stage strap-ons.

The purpose of this document is to present the results of the study. Section 2 contains a summary and a set of conclusions. The design aspects of the study are presented in Section 3 while Section 4 summarizes the cost data.

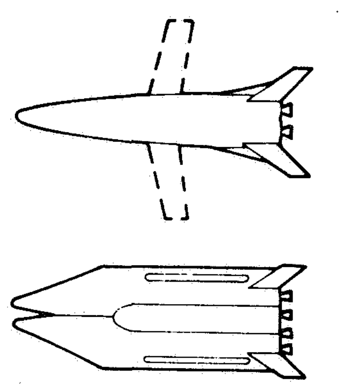
VEHICLE CONCEPTS



CONCEPT L



CONCEPT M



CONCEPT S

FIGURE 1-1

SECTION 2.0 SUMMARY AND CONCLUSIONS

Parametric cost trends for three future space shuttle concepts have been derived and are presented herein. Two of the shuttle concepts represent two stage vehicles developed by McDonnell Douglas under contract to the NASA. The third concept represents a basic two and one half stage configuration featuring identical orbiter and booster core vehicles plus zero stage strap-ons.

The basic intent of the sizing and performance analysis of Concept "S" was parametric in nature rather than optimization of the concept. The primary options involve core vehicle length and orbiter ΔV capability. The baseline configurations for this study considered constant length core vehicles for each of three payload sizes. The reference for the core vehicles was the 50,000 pound payload orbiter (165 foot length) as defined in the SAMSO STS Study. Thus the 50,000 pound payload configuration used in this study is the only configuration sized to near optimum conditions. By fixing core vehicle length, the ΔV capability of that vehicle designated as the orbiter is increased with decreasing payload since additional propellant volume is made available in lieu of payload for the 12,500 and 25,000 pound payload cases. In the case of the booster all payload volume is used for propellant. The other option available considered the ΔV capability of the orbiter. By holding the orbiter ΔV capability constant the core vehicles are scaled for each payload, assuming a constant payload density.

The results of the design phase of the study are reflected in the weight and cost statements given in Table 2-1. RDT&E cost estimates given in the table show that although Concept "S" weights are considerably greater than both concepts "L" and "M" the development costs are lower. This serves to illustrate the trade offs involved between the two design parameters (i.e., weight and cost). For each vehicle concept analyzed three distinct payload sizes were examined in the range from 10,000 to 50,000 pounds. On the basis of total gross launch weight Concept "S" is the heaviest configuration while Concept "M" yields the lowest weight configuration. In the case of Concept "S" between 45 and 60% of the total weight is attributable to the zero stage strap-ons. In addition total gross launch weight increases 2 to 3% when the zero stage is considered reusable. The highest weight Concept "S" configuration is the expendable/liquid zero stage case. In the case of Concept "S" each payload size is contained in a constant length vehicle equal to 165 feet.

TABLE 2-1

TOTAL GROSS LAUNCH WEIGHT AND RDT&E COST COMPARISONS
(Millions of Pounds) (Millions of Dollars)

Configuration	Payload (Lb)					
	12.5K(2)		25K		50K(3)	
	Weight	Cost	Weight	Cost	Weight	Cost
Concept "S"(1)						
Expendable/Solid	5.31	5,593	5.75	5,685	6.89	5,703
Reusable/Solid	5.41	5,629	5.86	5.722	7.07	5,739
Expendable/Liquid	5.09	5,746	5.54	5,854	6.74	5,909
Reusable/Liquid	5.16	5,732	5.65	5,838	6.92	5,886
Concept "L"	2.43	5,990	3.40	6,443	4.53	7,474
Concept "M"	1.49(4)	4,751(4)	2.85	6,269	4.10	7,379

(1) Baseline configuration (core vehicle length = 165 ft.)

(2) Payload equals 10K for Concept "L"

(3) Payload equals 45K for Concept "M"

(4) Weight and cost should be increased by 30% and 18% respectively to be consistent with 25K payload ground rules (Ref. Sections 3.3.6 and 4.6)

The baseline configuration for both Concepts "L" and "M" is the one containing the 25,000 pound payload. The weight statement given for the 12,500 pound payload case of Concept "M" is considered to be highly optimistic. This configuration was generated early in the NASA-MSC study and is not considered entirely consistent. Cursory investigations indicate that weight should be added for the contribution of the thermal/structural system and control surfaces. Further details are given in Section 3.3.6.

For each of the configurations cited in Table 2-1 total program costs were generated. The results of these cost studies for the baseline configurations are summarized in Table 2-2. Total program costs as defined herein include contributions made by Contract Definition, RDT&E, Investment and Operations phase. Both program office management and fee are included in each case. As indicated costs are given for three operational philosophies, namely, Integral Launch Reentry Vehicle (ILRV), Intermediate, and Business As Usual (BAU) considering traffic rates from 2.5 to 25 million pounds delivered to orbit. Operational philosophies are characterized by the vehicle turnaround times, made up of prelaunch and recertification activities, and subsequent inventory requirements.

The ILRV philosophy assumes that the launch, recovery and recertification take place at one location reducing to a minimum the amount of transportation. The other two philosophies assume the recovery is at existing sites, the recertification is at the factory, and the launch from either ETR or WTR. Launch operations range from limited testing and no check out in the ILRV philosophy to the full testing of present practice in the BAU philosophy. Recertification for ILRV includes limited scheduled maintenance and rapid flow time based upon long life systems. The BAU philosophy assumes extensive maintenance and inspection, based upon present systems, including full retesting during each cycle. The Intermediate philosophy is between the two extremes.

The results of the cost data presented in Table 2-2 shows that as payload increases cost differentials tend to be minimized whereas if payload decreases cost differentials tend to be maximized. For Concept "S" the minimum costs occur for the 50,000 pound payload case. This is not too surprising since the concept is near optimum for this payload. In the case of Concept "L" minimum costs are noted in the 25,000 pound payload case.

In general the following set of conclusions can be made relative to the cost data presented in this report:

1. Orbiter and Booster subsystem commonality saves $1 billion in RDT&E for Concepts "L" and "M".
2. Identical orbiter/booster saves $2 billion in RDT&E for Concept "S".
3. Major cost systems include the thermal/structural system, propulsion and avionics.
4. RDT&E and First Unit costs correlate with vehicle dry weight.
5. Procured hardware costs drive recertification costs.

TABLE 2-2

TOTAL PROGRAM COSTS
(Billions of 1969 Dollars)

Payload/Flight	Payload (Lb) 12.5K (2)				25K				50K (3)			
Total Payload	2.5M	8M	15M	25M	2.5M	8M	15M	25M	2.5M	8M	15M	25M
Concept "S" (1)												
ILRV (4)	7.1	9.8	13.4	18.0	6.4	8.0	10.1	12.8	6.2	7.4	8.3	9.9
Intermediate	12.0	24.8	39.7	60.0	9.0	16.0	24.0	35.3	7.4	11.2	15.8	22.0
BAU (5)	20.1	44.5	71.7	107.0	13.7	27.6	42.9	63.0	8.1	18.3	27.0	38.5
Concept "L"												
ILRV	7.0	8.9	11.1	14.5	6.8	7.7	9.0	10.6	7.7	8.5	8.9	9.8
Intermediate	11.5	22.2	35.3	52.3	8.8	14.3	20.7	28.8	8.9	12.3	16.4	21.4
BAU	18.7	39.5	62.7	93.5	13.0	24.1	36.4	52.5	11.6	19.3	27.4	38.3
Concept "M"												
ILRV	5.5	6.8	8.5	9.9	6.7	7.6	8.9	10.5	7.6	8.4	9.4	10.4
Intermediate	8.7	16.4	25.5	37.7	8.9	14.7	21.2	27.9	9.2	13.2	18.0	24.3
BAU	13.7	28.4	44.9	66.4	13.4	25.2	38.2	55.2	12.5	21.5	31.2	44.3

(1) Baseline configuration (core vehicle length = 165 ft), expendable/solid zero stages
(2) Payload equals 10K for Concept "L"
(3) Payload equals 45K for Concept "M"
(4) ILRV -Integral Launch Reentry Vehicle
(5) BAU - Business As Usual

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SECTION 3.0 DESIGN ANALYSIS

Definition of design data, in a format required by the cost model, has been generated for two versions of a fully reusable two stage shuttle and for a, two and one half stage shuttle concept and is presented in this section of the report. The two stage configurations designated Concepts "L" and "M" represent recently completed studies performed for the NASA-LRC and NASA-MSC respectively. The basic core vehicles for the two and one half stage configuration designated Concept "S" was based on the use of the orbiter vehicle defined in a recent study for SAMSO/AFSC. In Concept "S" both core vehicles are identical. The additional ΔV required to achieve orbit is provided by zero stage strap-ons. The results of the design analysis for Concepts "S", "L" and "M" are found respectively in Sections 3.1, 3.2 and 3.3.

3.1 Analysis of Concept "S" - The analysis of Concept "S" consisted of defining a set of ground rules and assumptions (Section 3.1.1) conducting a sizing and performance analysis (Section 3.1.2), providing detail descriptions of the major subsystems (Sections 3.1.3 thru 3.2.5) and the generation of a detailed weight statement. (Section 3.2.6).

3.1.1 Ground Rules and Assumptions - The general ground rules and assumptions applied to the analysis of Concept "S" are listed below. Additional specific information relative to the core vehicles used in this concept can be obtained from Reference 1.

- o Orbiter and Booster Stages are identical.
- o Baseline Orbiter/Booster stage same as baseline orbiter as defined in SAMSO/AFSC STS study under contract F047-01-69-C-0380.
- o Utilization of zero stage strap-ons considering solid versus liquid and expendable versus reusable capability.
- o Payload Considerations
  50,000 lb in a 15 ft dia., 60 ft long envelope
  25,000 lb in a 15 ft dia., 30 ft long envelope
  12,500 lb in a 15 ft dia., 15 ft long envelope
- o High chamber pressure bell nozzles used for main propulsion system on both core vehicles.
- o Boost engines are the same size for both core stages for any one configuration.
- o Boost propellants are LOX/LH_2.
- o Parallel burn of all engines with propellant transfer between core vehicles.

- On-orbit ΔV capability equal to 2000 fps
- Orbit maneuver system propellant - LOX/LH_2
- Attitude control system propellant - GO_2/GH_2
- Landing assist engine - turbofan for both stages
- Nominal orbit altitude of 270 nautical miles and an inclination of 55°
- Insertion orbit of 45 x 100 nautical miles
- Mission duration - 7 days
- Both core vehicles have a 2 man crew
- Crew will operate in a shirtsleeve environment
- Thermo-structural system designed to a 3 g normal load factor and a 2200°F temperature limit
- Orbiter entry angle of attack equal to 20° and 50°
- Prime power for orbiter and booster is supplied respectively by H_2-O_2 matrix type fuel cells and rechargeable AgO-2n batteries
- Three completely independent hydraulic subsystems

3.1.2 Sizing and Performance Analysis of Concept "S" - This section of the report presents the results of the sizing and performance analysis conducted on Concept "S". The performance aspect of the study consisted of conducting various aero/thermodynamic analyses for the purpose of (1) determining launch phase velocity losses, (2) establishing trajectories for both a low and high angle of attack entry, and (3) determining the adequacy of the vehicles thermal protection system in meeting the above named entry conditions.

The sizing portion of the study dealt mainly with the establishment of the requirements for zero stage boosters. In accomplishing this task the analyses was divided into three phases. The first phase was concerned with developing basic sizing ground rules and data for subsequent generation of baseline zero stages. The second phase was performed to demonstrate the effect of various sizing options on the concept and to select a baseline system. The third phase was generation of baseline zero stage designs. In addition, the baseline data was extrapolated to produce approximate sizing data for other options.

3.1.2.1 Concept Description - Concept "S" consists of two identical lifting body core vehicles, one serving as a booster and the other as an orbiter, arranged in a siamese manner wherein their bottom surfaces are adjacent one to another from launch to separation. Unless excessively large vehicles are used, the impulsive velocity capability of the two stages is not sufficient to achieve orbit insertion of one of the vehicles. Therefore, zero stage boosters (either solid or pressure fed liquid) are incorporated to provide the additional velocity increment (ΔV) required.

The basic core vehicle shown in Figure 3-1 is a variable geometry arrangement defined by a conic planform forward section which develops into parallel sides as it continues aft. The planform terminates with lower fixed fins and movable upper control surfaces. The upper body is contoured to a zero flow shadow angle at the nominal hypersonic angle of attack. The body cross section is trapezoidal. Variable geometry wings are stowed parallel within the upper body and deploy forward for subsonic cruise and landing.

Specifically the core vehicles are identical to the baseline orbiter vehicle as defined in the SAMSO STS study, Reference 1. This baseline orbiter vehicle is 165 feet long and has a payload capability of 50,000 pounds. The payload cannister is 15 feet in diameter and 60 feet long. In addition to this payload size two other payload configurations were considered in this study. These included a 12,500 pound payload packed in a 15 foot diameter by 15 foot long cannister and a 25,000 pound payload sized in a 15 foot diameter by 30 foot long cannister. In each payload case the core vehicle length was held constant at 165 feet. Although the configurations just described were considered as baseline cases other concepts involving variable length and fixed ΔV core vehicles for the same payload sizes were investigated on a parametric basis.

As mentioned previously each core vehicle was identical. This was done to maintain commonality and reduce overall program costs although some weight penalties were incurred. This commonality groundrule was adhered to with regard to all major subsystems such as the thermal/structural system, avionics, propulsion, etc. The one exception to this involved the utilization of the payload bay area. In the case of that core vehicle designated as a booster a drop-in fuel tank was used in lieu of payload as shown in Figure 3-2. For the case of the 50,000 pound payload orbiter vehicle all of the volume available is taken up by the payload itself. In the 12,500 and 25,000 payload orbiter cases drop-in fuel tanks were used in lieu of payload for the remaining volume capability, as was done on the case of the booster. Alternate payload/propellant arrangements for the orbiter are shown in Figure 3-3.

Each core vehicle contains two booster engines and propellant transfer was assumed between vehicles such that all engines burn simultaneously at lift-off.

BASIC CORE VEHICLE FOR CONCEPT "S"

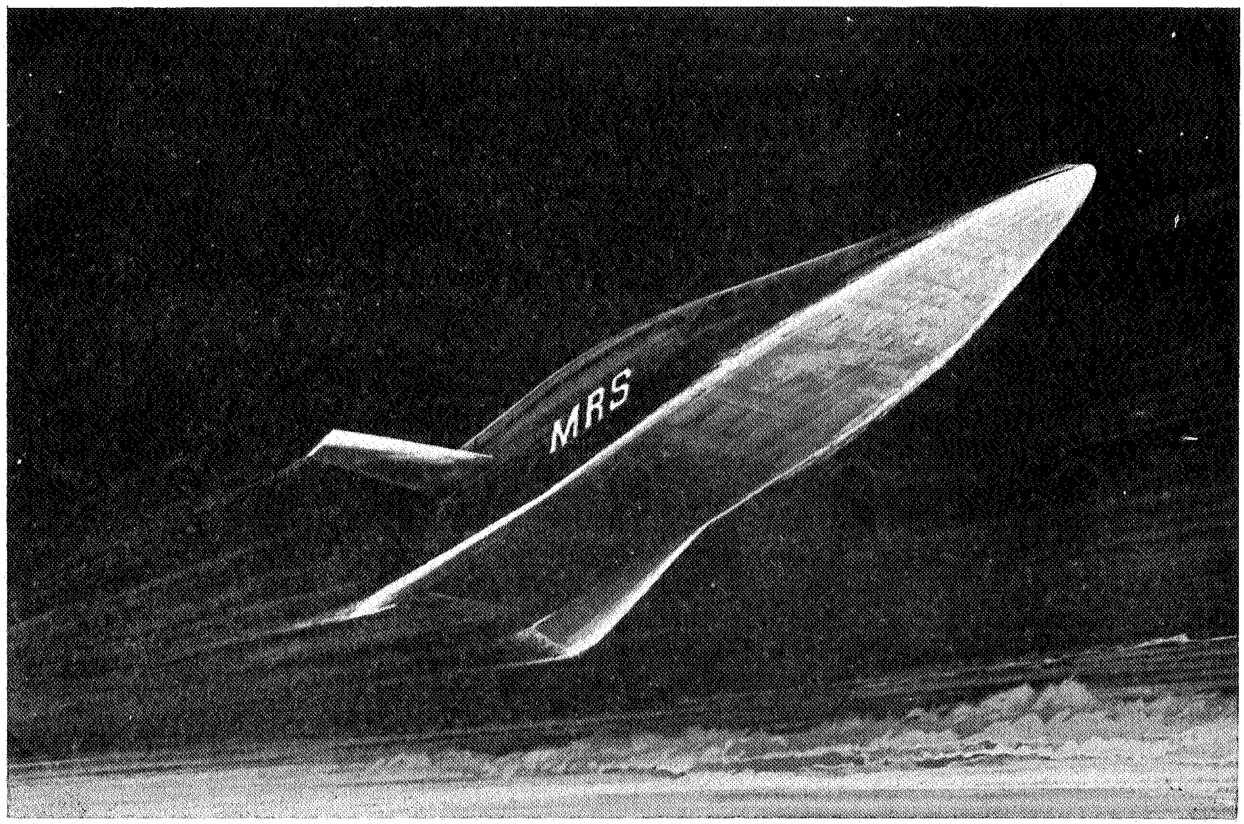


FIGURE 3-1

BOOSTER-DROP IN PROPELLANT TANK

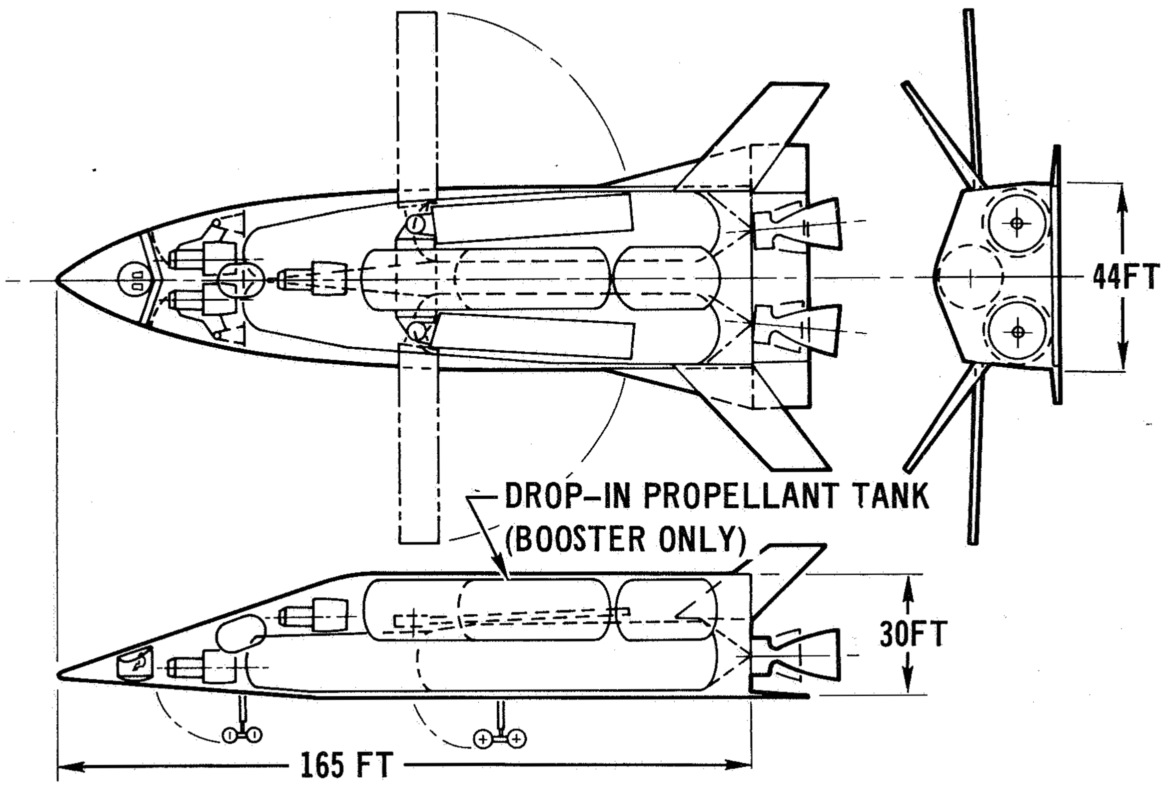


FIGURE 3-2

ORBITER—ALTERNATE PAYLOAD/PROPELLANT ARRANGEMENTS

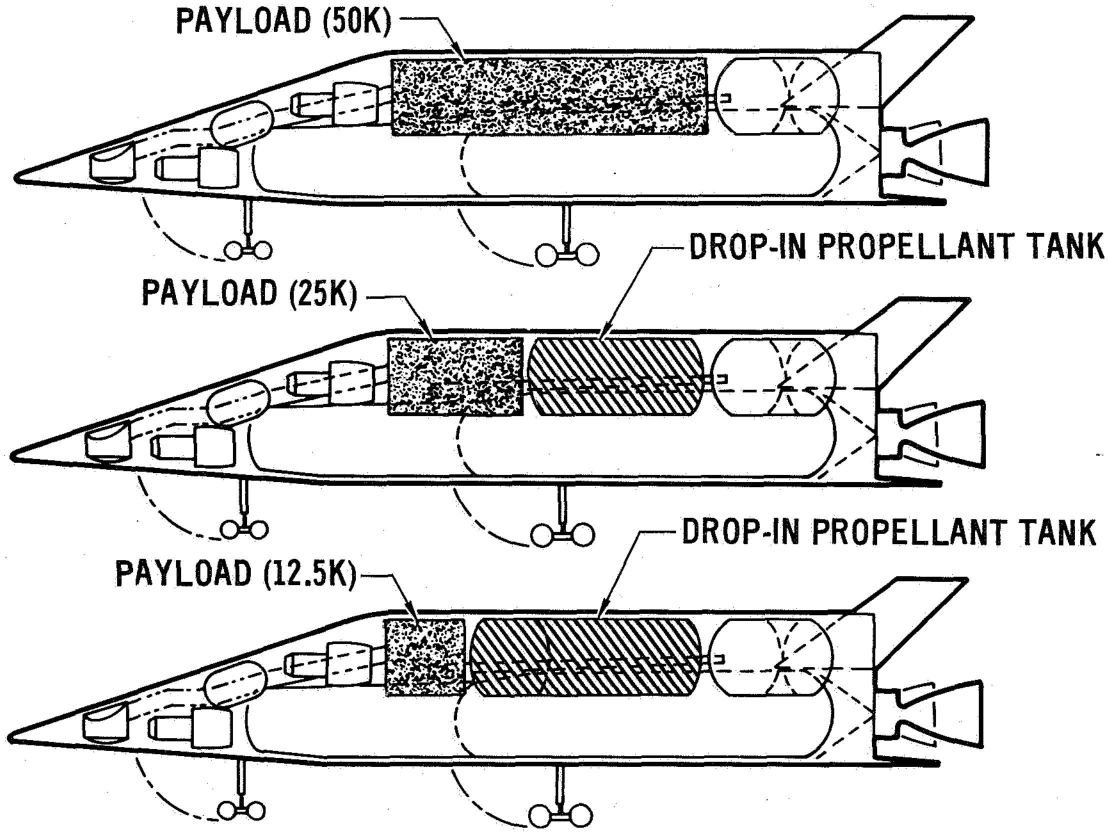


FIGURE 3-3

The transfer of propellant was such that all booster propellant was used during launch leaving the orbiter propellant tanks fully fueled at core vehicle staging. The remaining propulsive force during launch was provided by the zero stage strap-ons. Schematic diagrams of both a solid and liquid pressure fed configuration is shown in Figures 3-4 and 3-5 respectively. The solid zero stage configuration features four strap-ons each of which is mounted to the side of the vehicle. Each zero stage is a completely self contained rocket system. The liquid pressure fed system features a Mono-methyl Hydrazine and Nitrogen tetroxide tank mounted parallel to each other on each side of the core vehicles. Cross feed is provided enabling parallel burn of engines mounted at the end of each tank. Both types of zero stages were sized assuming a requirement for a JATO function only and that all control is provided by the spacecraft.

Detailed descriptions of the various subsystems comprizing the core vehicles can be found in other sections of this report.

SOLID ZERO STAGE LAUNCH CONFIGURATION

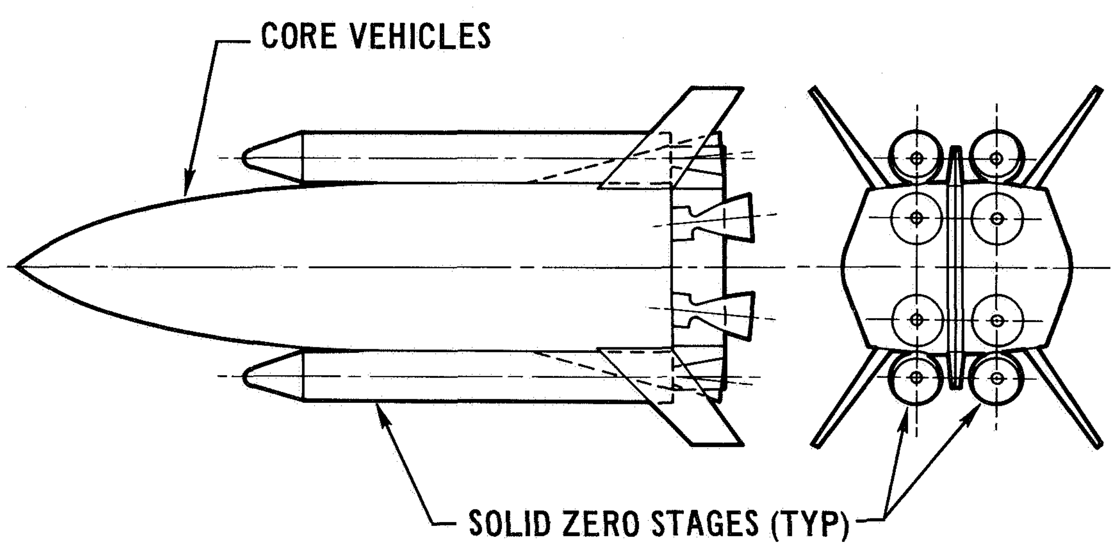


FIGURE 3-4

LIQUID—ZERO STAGE LAUNCH CONFIGURATION

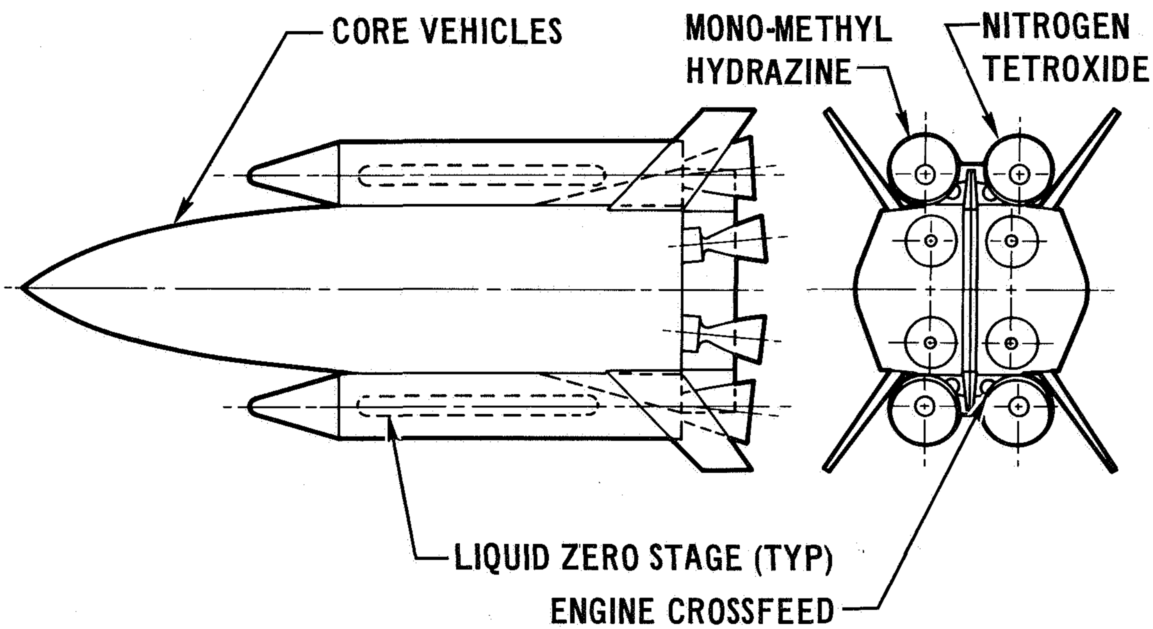


FIGURE 3-5

3.1.2.2 Aero/Thermodynamic Performance Analysis - The primary objectives of the aero/thermodynamic performance analysis conducted during this study were (1) to determine launch phase velocity losses, (2) establish trajectories for both a low and high angle of attack entry and (3) determine the adequacy of the thermal protection system as defined in the SAMSO study in meeting these entry conditions. These analyses were performed solely for the boost and entry regimes for the nominal mission described in Figure 3-6. Zero stage entries were not studied in detail. Estimates were made, however, of the down range capability in order to establish approximate requirements for tow back range in the event the zero stage would be reused. Details as to the aerodynamic characteristics of the core vehicles can be found in Reference 1.

The prime intent of the analysis was to yield a minimum weight system, with consideration for the atmospheric exit and entry environment, while maintaining a high confidence in some of the basic data generated by related studies. Mission and contractual considerations resulted in the establishment of several study ground rules and constraints. These include but are not necessarily limited to the following: (1) insertion at perigee of a 45 x 100 nautical mile orbit, (2) Hohmann transfer to 270 nautical mile circular orbit with an inclination of 55 degrees, (3) axial load factor was constrained not to exceed 4g's, (4) a thrust-to-weight ratio at lift-off equal to 1.35, (5) parallel burn of all engines at lift-off, (6) throttle settings for engines were constrained to be no less than 10% of maximum and (7) entry at both low and high angle of attack.

A. Launch Phase - The launch phase as defined herein refers to that period of flight extending from lift-off to core vehicle staging. For this phase, twelve configurations; comprising 3 payloads, solid versus liquid and expendable versus reusable zero stages; were analyzed using numerical analyses techniques in trajectory simulations. The trajectory program used utilized a rotating spherical earth model and the 1962 U.S. Standard Atmosphere. Gravity turns were employed prior to booster stage separation while a thrust vectoring program, derived by calculus-of-variations method, was used for the orbiter to achieve the desired insertion conditions.

Thrust Modulation - The profile of thrust versus time used in the analyses was established on the basis of the study constraints defined previously. The sizing analyses, as discussed in Section 3.1.2.3, indicated that for a given ideal velocity requirement, the gross launch weight of the system was minimized

MISSION PROFILE

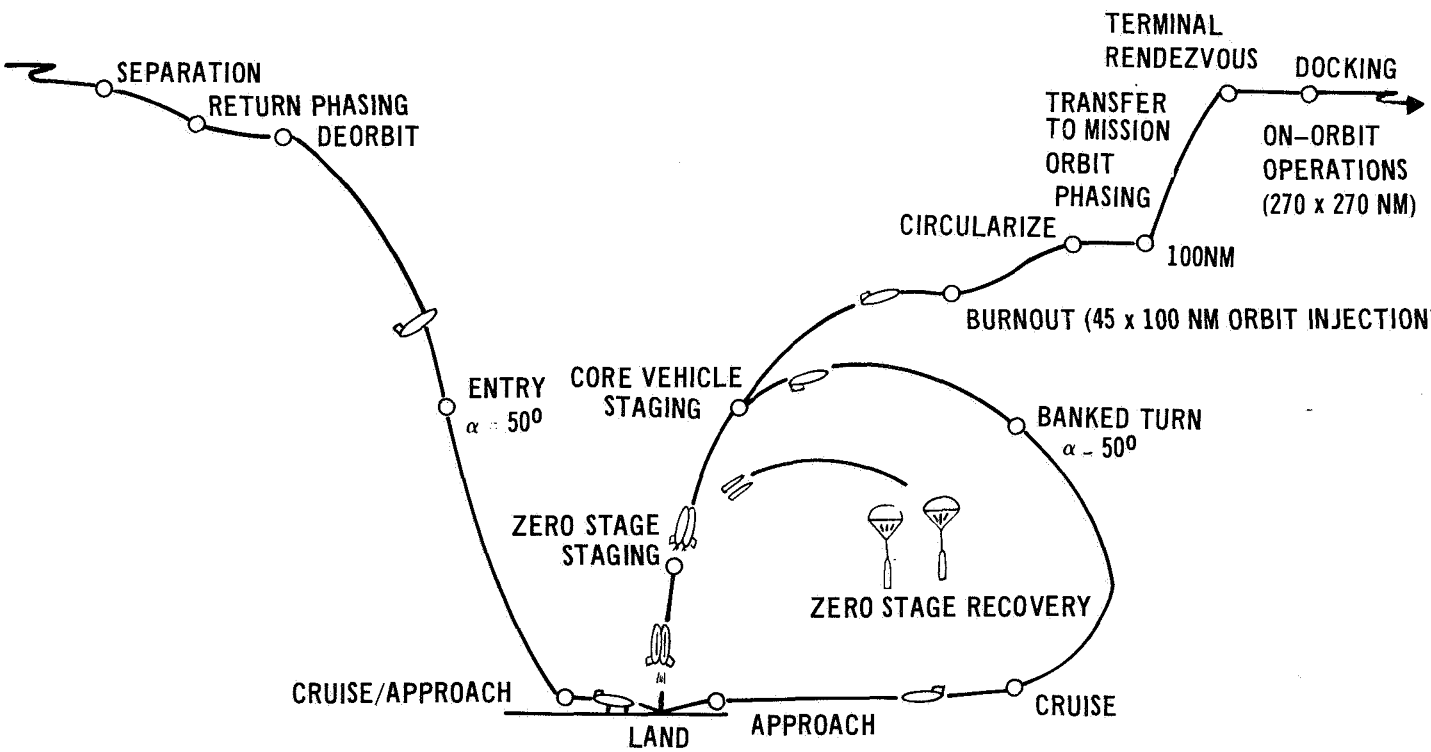


FIGURE 3-6

when the throttle setting on the core vehicles was minimized. Thus ignoring the variation in launch phase losses, idle power in the core vehicles is the optimum throttle setting prior to strap-on burnout.

However, with such a throttle setting it was found that the peak dynamic pressure exceeded structural limits. Therefore, the initial thrust of the primary stages was set to be 30% of the maximum and the strap-ons were then sized to bring the total thrust to weight ratio to 1.35. This allowed a throttling back from the 30% level to idle power at strap-on burnout and a lower dynamic pressure resulted. In the case of the 50,000 pounds payload configuration the peak dynamic pressures were still quite high. However, the assurance that it could be reduced with greater throttling and the estimated small changes in other important variables prompted the decision not to re-size the vehicle or recalculate the trajectories.

After the strap-ons have burned out, throttle setting no longer affects ideal velocity. Hence, the primary stages are burned at full throttle after strap-on burnout except when a reduction in thrust is needed to limit the thrust-to-weight ratio to 4.

Launch Sequence - All launch trajectories followed the same sequence of events to insure a fair comparison between them although actual flight times varied. Figures 3-7 and 3-8 show time histories of significant parameters for a representative launch trajectory. The flight sequence is as follows: Lift Off vertically with a 1.35 thrust-to-weight ratio. Begin a thrust reduction in the primary stages at lift-off so that they are at idle power when strap-on burnout occurs. At 20 seconds a pitch program is initiated that moves the velocity vector 10 degrees from vertical at 30 seconds. Between 30 seconds and core stage separation a gravity turn is performed. At 92 seconds strap-on fuel is exhausted. The strap-ons are then jettisoned and the thrust level of the primary stages is increased to full power. Using fuel transfer between core stages, burn is maintained until the booster stage fuel is exhausted leaving the orbiter fully loaded. At 200 seconds the empty booster stage separates and begins its return to the launch site. The orbiter continues in ascent flight using thrust vectoring to optimize the trajectory. At about 390 seconds the thrust-to-weight ratio reaches 4g's. From that time to burnout, thrust is modulated to maintain this constant load factor. Insertion at perigee of a 45 x 100 nautical mile orbit occurs at 409 seconds.

REPRESENTATIVE LAUNCH TRAJECTORY
PART I

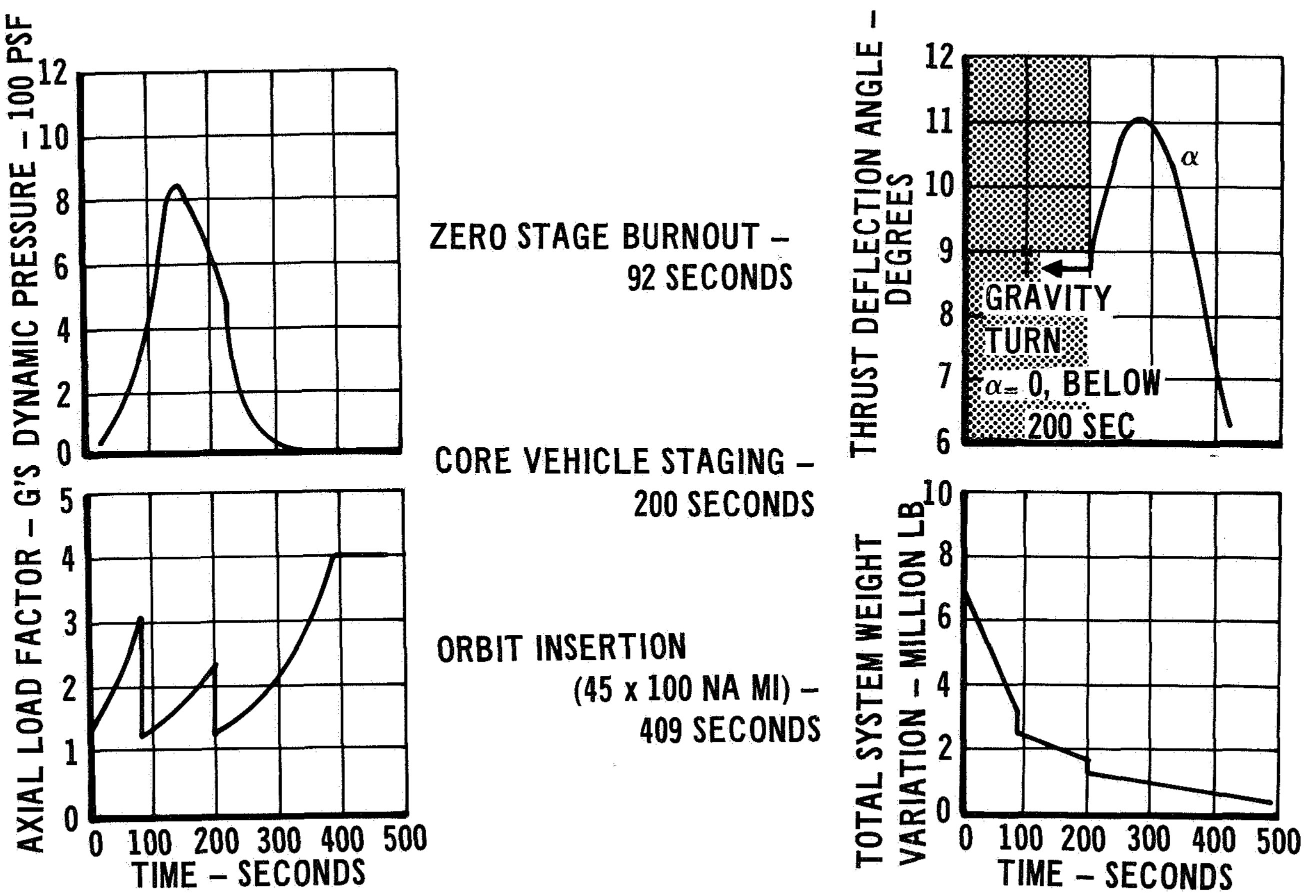


FIGURE 3-7

REPRESENTATIVE LAUNCH TRAJECTORY PART II

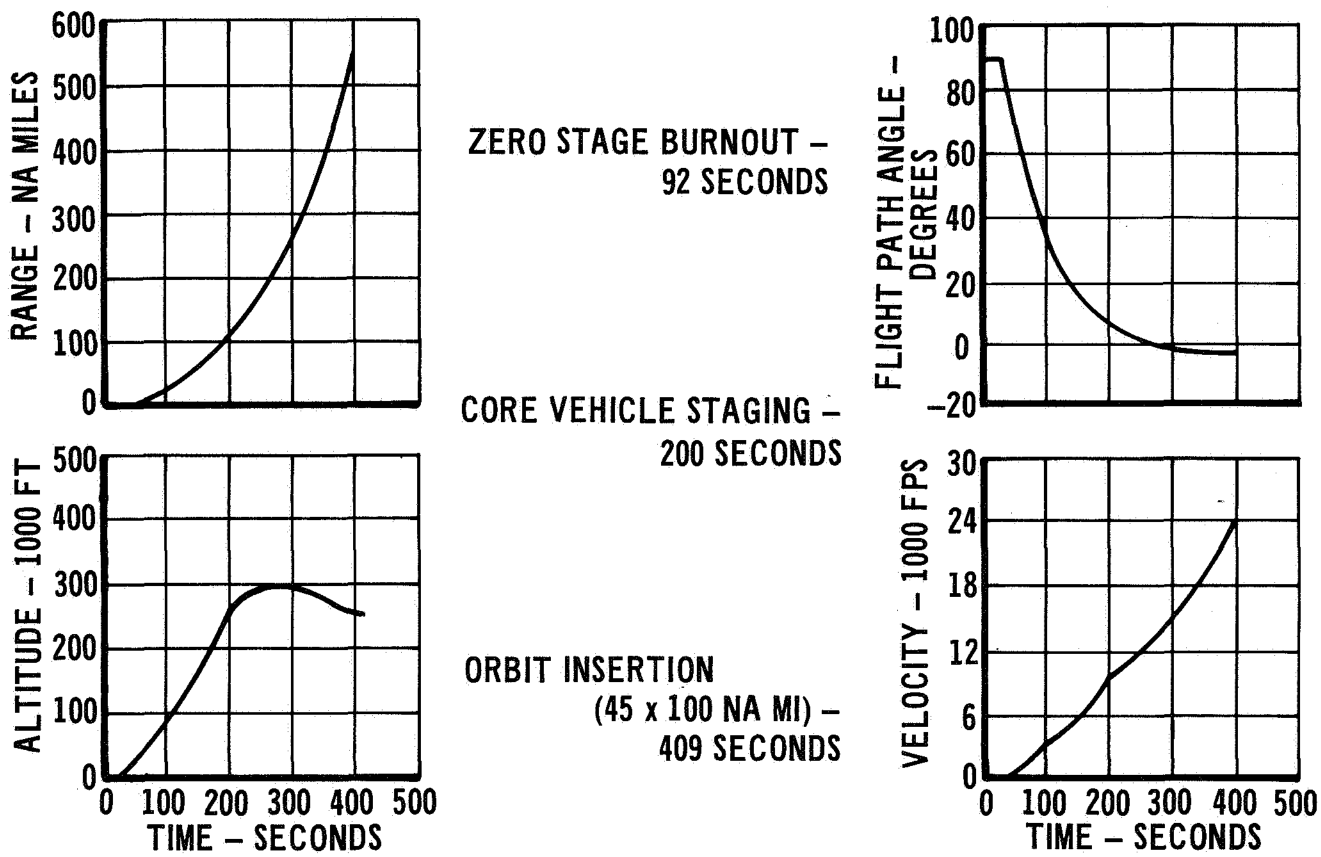


FIGURE 3-8

During launch the only aerodynamic force significant in determining performance is drag. The drag coefficients used in this study were based on the data of Reference 1, appropriately scaled by the difference in frontal areas. A detailed investigation of drag was beyond the scope of the study. Figure 3-9 shows a plot of drag coefficient, C_D, as a function of Mach number. The reference area used was the total frontal area of the configuration.

Total ΔV Budget - Once a mission had been defined, the ideal mission velocity budget was estimated. The total mission velocity budget that must be built in the launch configuration is the sum of (a) injection velocity, (including the Earth inertial component), (b) nominal ascent phase losses, and (c) flight performance reserve. The size of vehicle required to provide this velocity is a function of stage structure fraction, specific impulse and the distribution of velocity between the stages. Velocity losses have been determined to be a function of staging velocity and may significantly effect overall vehicle sizing. The purpose of this section is to establish the velocity losses and determine the impact on the sizing analysis.

The nominal ascent phase velocity budget is equal to the sum of the losses and the velocity required to inject the orbiter plus payload into a reference 45 x 100 NM orbit. In each case analyzed the vehicle required a total of 25,885 ft/sec of actual velocity at insertion. This included 886 ft/sec which was supplied by the earth's inertial component. Since the ideal mission velocity is a constant, the nominal ascent phase velocity budget variation is identical to the velocity loss variation.

Ascent phase losses consist of velocity increments required to overcome the effects of (a) gravity, (b) aerodynamic drag forces, (c) thrust vector maneuvering, and (d) nozzle back pressure. Table 3-1 shows a breakdown of these velocity losses for each of the twelve (12) constant length configurations analyzed. Table 3-2 repeats the total losses and includes two significant trajectory parameters; namely, peak dynamic pressure and strap-on burn time. These two parameters are significant in that they determine the shape of the thrust-to-weight ratio history and consequently the magnitude of the gravity loss. The gravity loss in turn affects the other three losses because of the trade-off between them. For example, gravity loss can be made small by flying a very low trajectory, however, drag and back pressure losses would increase accordingly.

LAUNCH PHASE DRAG COEFFICIENT

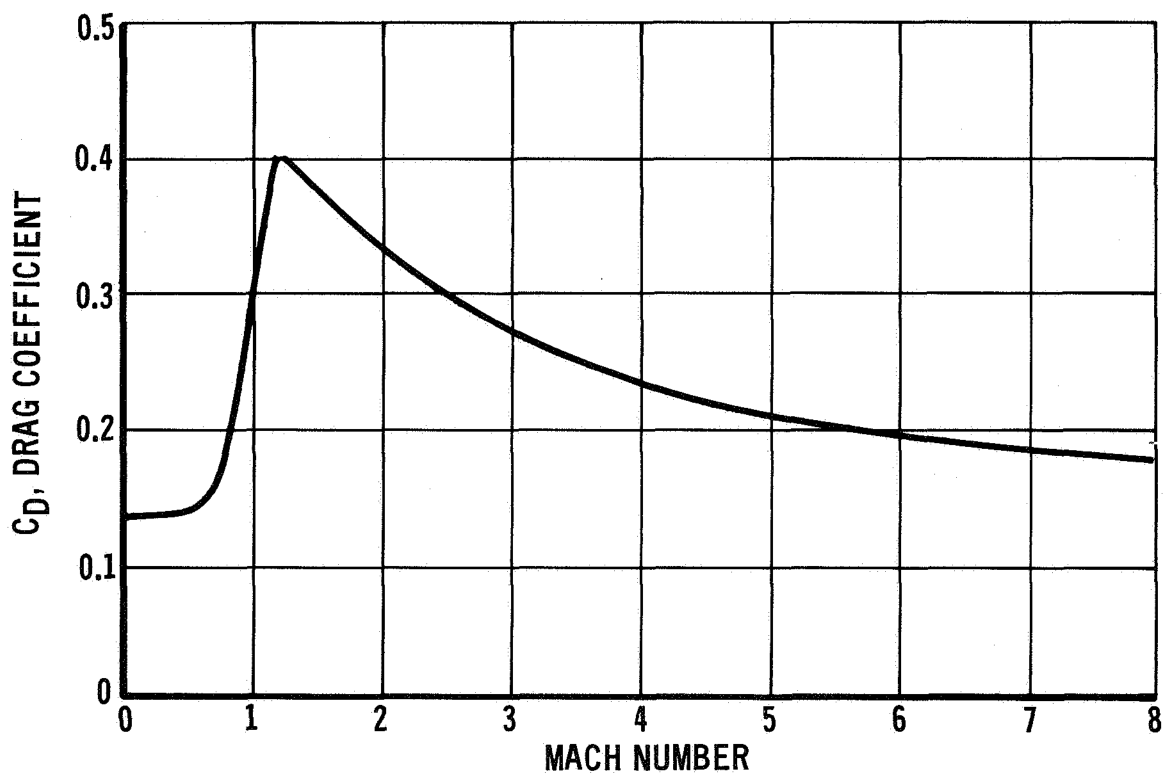


FIGURE 3-9

TABLE 3-1

LAUNCH PHASE VELOCITY LOSS SUMMARY – PART I

PAYLOAD (LB)	TYPE OF STRAP-ON	GRAVITY LOSS (FT/SEC)	DRAG LOSS (FT/SEC)	NOZZLE BACK PRESSURE LOSS (FT/SEC)	MANEUVERING LOSS (FT/SEC)	TOTAL LOSSES (FT/SEC)
50,000	SOLID EXPENDABLE	4018	290	462	247	5017
50,000	SOLID REUSABLE	3998	286	459	265	5008
50,000	LIQUID EXPENDABLE	3903	361	696	227	5187
50,000	LIQUID REUSABLE	3915	354	692	218	5179
25,000	SOLID EXPENDABLE	4388	289	498	288	5463
25,000	SOLID REUSABLE	4399	287	493	307	5486
25,000	LIQUID EXPENDABLE	4242	337	717	296	5592
25,000	LIQUID REUSABLE	4256	333	713	286	5588
12,500	SOLID EXPENDABLE	4733	274	511	283	5801
12,500	SOLID REUSABLE	4774	269	501	277	5821
12,500	LIQUID EXPENDABLE	4514	312	723	270	5819
12,500	LIQUID REUSABLE	4515	312	720	299	5846

TABLE 3-2

LAUNCH PHASE VELOCITY LOSS SUMMARY PART II

PAYLOAD (LB)	TYPE OF STRAP-ON	GROSS LIFT-OFF WEIGHT (LB)	PEAK DYNAMIC PRESSURE (LB/FT^2)	STRAP-ON BURN TIME (SEC)	TOTAL LOSSES (FT/SEC)
50,000	SOLID EXPENDABLE	6,891,290	774	98.2	5017
50,000	SOLID REUSABLE	7,064,310	773	98.2	5008
50,000	LIQUID EXPENDABLE	7,277,550	875	95.8	5187
50,000	LIQUID REUSABLE	7,500,040	877	95.8	5179
25,000	SOLID EXPENDABLE	5,455,200	682	79.0	5463
25,000	SOLID REUSABLE	5,557,560	684	79.0	5486
25,000	LIQUID EXPENDABLE	5,731,570	780	80.2	5592
25,000	LIQUID REUSABLE	5,842,160	782	80.2	5588
12,500	SOLID EXPENDABLE	5,057,370	634	70.7	5801
12,500	SOLID REUSABLE	5,142,460	636	70.7	5821
12,500	LIQUID EXPENDABLE	5,086,550	729	69.9	5819
12,500	LIQUID EXPENDABLE	5,161,170	731	69.9	5846

Comparison of the data, given in Tables 3-1 and 3-2, shows that between 75 and 80 percent of total losses is attributable to gravity effects. Drag and maneuvering losses are relatively constant over the payload spectrum whereas nozzle back pressure losses increase with decreasing payload. As payload decreases total velocity losses increase due to the shorter burn time of the strap-ons and lower q_{max} conditions. Liquid strap-on configurations have greater velocity requirements than corresponding solid strap-on configurations due to increases in back pressure and drag losses. These losses, however, are somewhat offset by reductions in gravity and maneuvering losses. Any variation in velocity requirement due to reusability of the strap-ons is negligible.

One of the obvious factors that affects the vehicle's payload capability is the in-orbit maneuver propellant required to support a typical space station/base resupply mission. Similarly, the propellant required is affected by several variables, one of which is the ΔV maneuvering budget. A ΔV maneuvering budget for a selected baseline mission is composed of the following: a basic minimum ΔV value that results from optimum or minimum energy transfer maneuver sequences including deorbit; and additional ΔV margins which are included for operational considerations, guidance and navigation dispersions, and non-optimum phasing situations. All the items included in these two groups are in turn affected by a selected set of basic assumptions and guidelines. As a result, different on-orbit ΔV budgets ranging from approximately 1200 fps to 5000 fps have been identified in past studies for the spacecraft depending on the mission requirements. For the purposes of this study a 2000 fps flight performance reserve was established as being representative of a typical resupply mission. A breakdown of the various elements making up this ΔV requirement is shown in Figure 3-10.

B. Booster Entry Analysis - Two control angles, namely; bank angle and angle of attack were chosen to minimize cruise back range of the booster. These angles were constrained by both a 3g normal load factor and a 2200°F temperature limit as adopted from the SAMSO study. Concept "S" relies heavily on the results of Concept "L" in this regard and the reader is referred to Reference 2 for a discussion of the analysis involved in choosing the control angles.

Entry Sequence - Immediately after separation of the core vehicles the booster is flown inverted at 50 degrees angle of attack. The reasons for this attitude is to maximize both drag and the downward lift. Increasing drag subsequently decreases velocity and hence shortens range because the velocity

NOMINAL ΔV BUDGET FOR BASELINE MISSIONS

	ΔV–FPS
MINIMUM REQUIREMENTS	
• TRANSFER AND GROSS RENDEZVOUS	660
• TERMINAL RENDEZVOUS	60
• STATIONKEEPING, DOCK, SEPARATION	30
• RETURN PHASING	55
• DEORBIT	485
RESERVES AND DISPERSIONS	
• INSERTION AND GROSS RENDEZVOUS	120
• TERMINAL RENDEZVOUS	90
• DEORBIT RESERVE	50
• AVAILABLE FOR MISSION VERSATILITY	450
TOTAL	2000

FIGURE 3-10

cannot be used to return the vehicle to the launch site but only to carry it further away. This is true because the turning capability of the vehicle is such that it can not get turned back towards the launch site while still at good range-making speeds. Maximum downward lift also shortens range by decreasing velocity since it brings the vehicle more quickly into the dense atmosphere of low altitudes.

The vehicle remains inverted as it passes through apogee. When a negative flight path angle of 3 degrees is reached, the vehicle is rolled to an upright attitude. Continued inverted flight would indeed shorten range as discussed above. However, if inverted flight is maintained much longer, the vehicle will not recover and either violate temperature or load factor constraints. In addition, the pay-off in range becomes small if inverted flight is maintained past some flight path angle. Concepts "L" and "M" indicated that the flight path should be between 3 and 6 degrees. Three degrees was chosen for Concept "S" because of the less severe environmental conditions encountered.

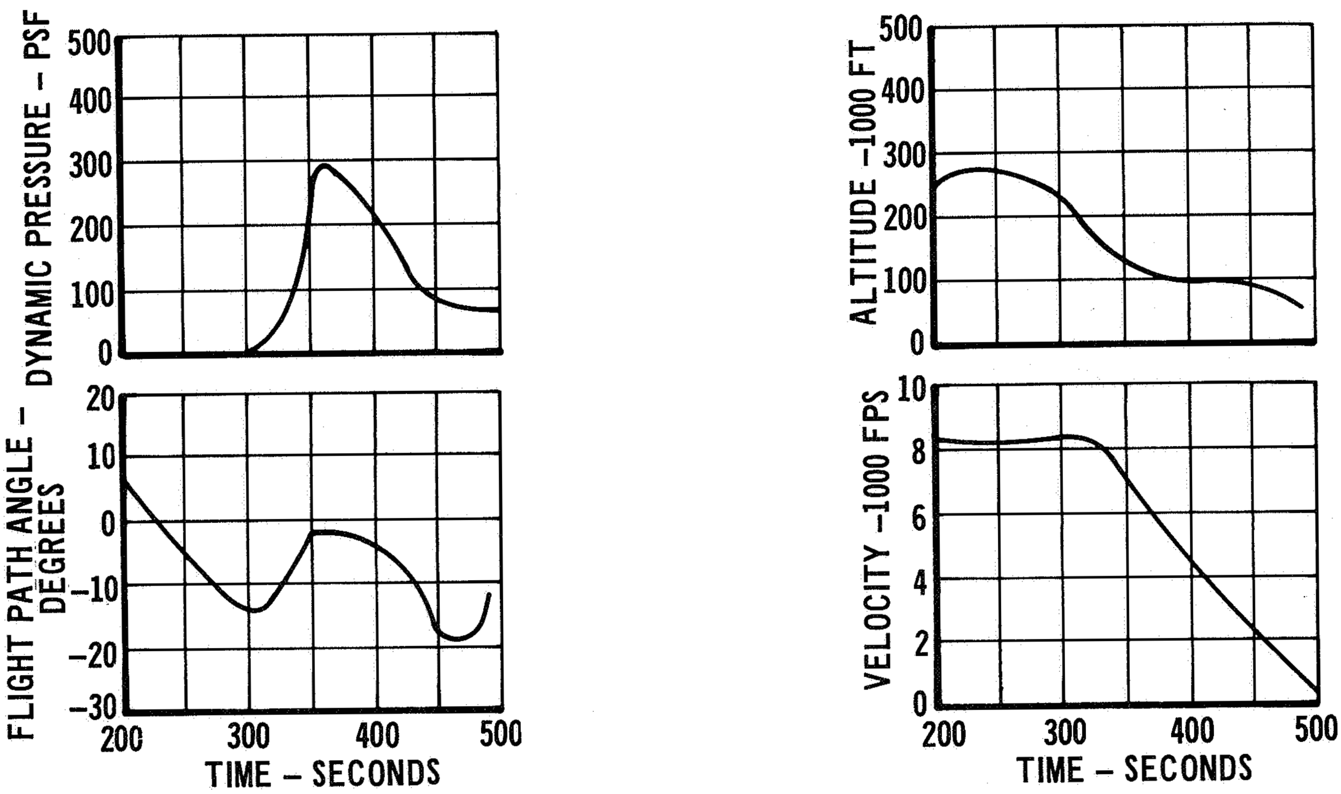
When the vehicle has pulled up to a negative 2 degree flight path angle it has acquired a maneuvering margin with respect to load factor and temperature constraints. It can then be banked for the purposes of (1) reducing L/D and hence shortening range and (2) changing the detection of flight back toward the launch site. Seventy degrees was chosen for the bank angle in this portion of flight. Previous studies determined that this angle was near the maximum allowable without inducing a rapid fall and a large increase in peak dynamic pressure.

Figure 3-11 and 3-12 present time histories of significant parameters for a representative entry. In this case a 50,000 lb. payload configuration was chosen since it represents the most severe environment encountered.

<u>Entry Summary</u> - Altitude/velocity and altitude/range profiles for each of the three payloads investigated during this study are shown respectively in Figures 3-13 and 3-14. In Figure 3-13 a 1600°F isotherm is included to show that in no case is there a temperature porblem. The normal load factor constraint is also satisfied being equal to 3g's in the region where angle of attack is less than 50 degrees and less than 3g's elsewhere. The particular trajectories shown are for configurations with expendable solid strap-ons.

The required cruise back capability of the booster is indicated in Figure 3-14 as the distance from the launch site at the end of the entry maneuver. As shown cruise back ranges vary from 240 to 365 nautical miles, depending on

BOOSTER ENTRY TRAJECTORY
PART I

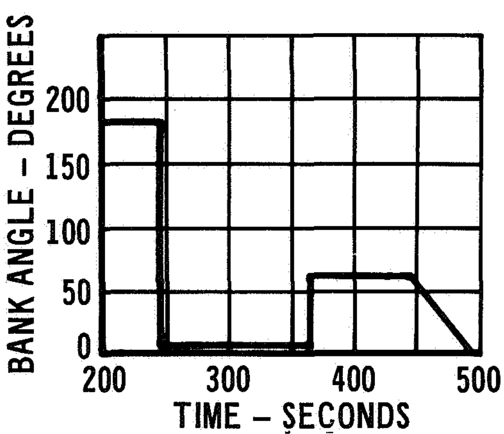


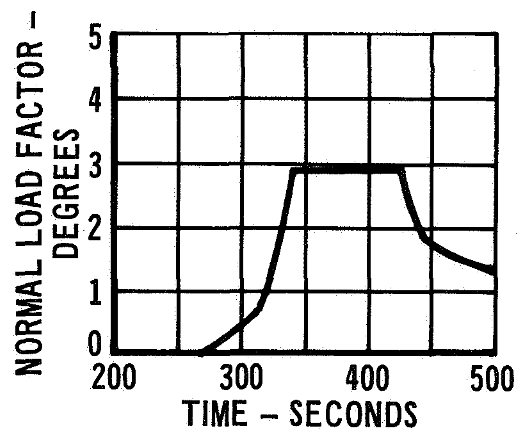
VEHICLE SEPARATION – 200 SEC
END INVERTED FLIGHT – 250 SEC
BEGIN ANGLE OF ATTACK – 340 SEC
MODULATION

BEGIN 70° BANK ANGLE – 365 SEC
END ANGLE OF ATTACK MODULATION – 425 SEC
BEGIN TERMINAL APPROACH –490 SEC

FIGURE 3-11

BOOSTER ENTRY TRAJECTORY
PART II





VEHICLE SEPARATION – 200 SEC
END INVERTED FLIGHT – 250 SEC
BEGIN ANGLE OF ATTACK – 340 SEC
MODULATION

BEGIN 70° BANK ANGLE – 365 SEC.
END ANGLE OF ATTACK MODULATION – 425 SEC
BEGIN TERMINAL APPROACH – 490 SEC

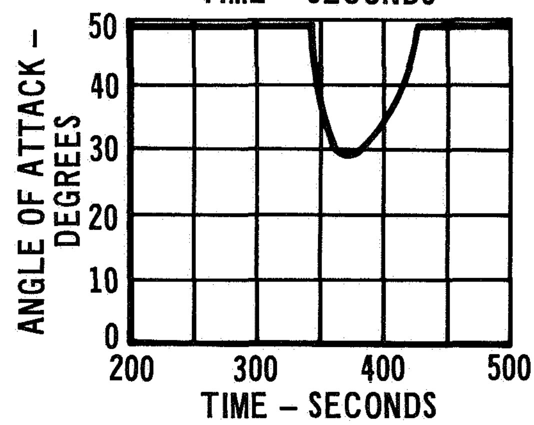


FIGURE 3-12

BOOSTER ENTRY
ALTITUDE/VELOCITY PROFILES

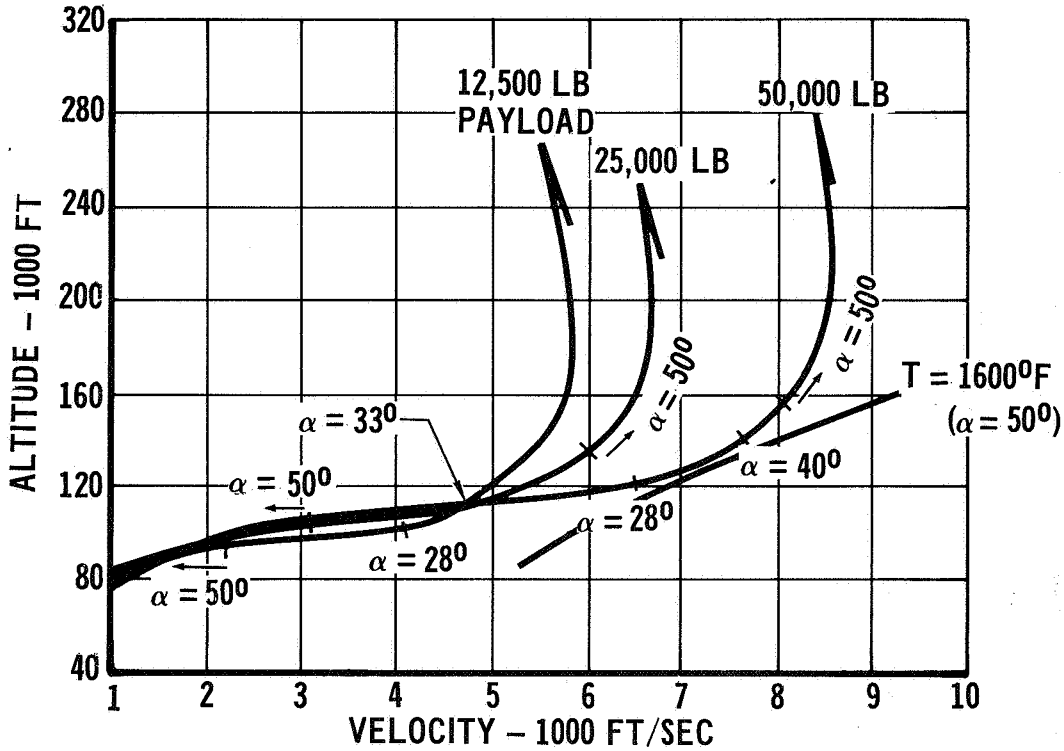


FIGURE 3-13

BOOSTER ENTRY ALTITUDE/RANGE PROFILES

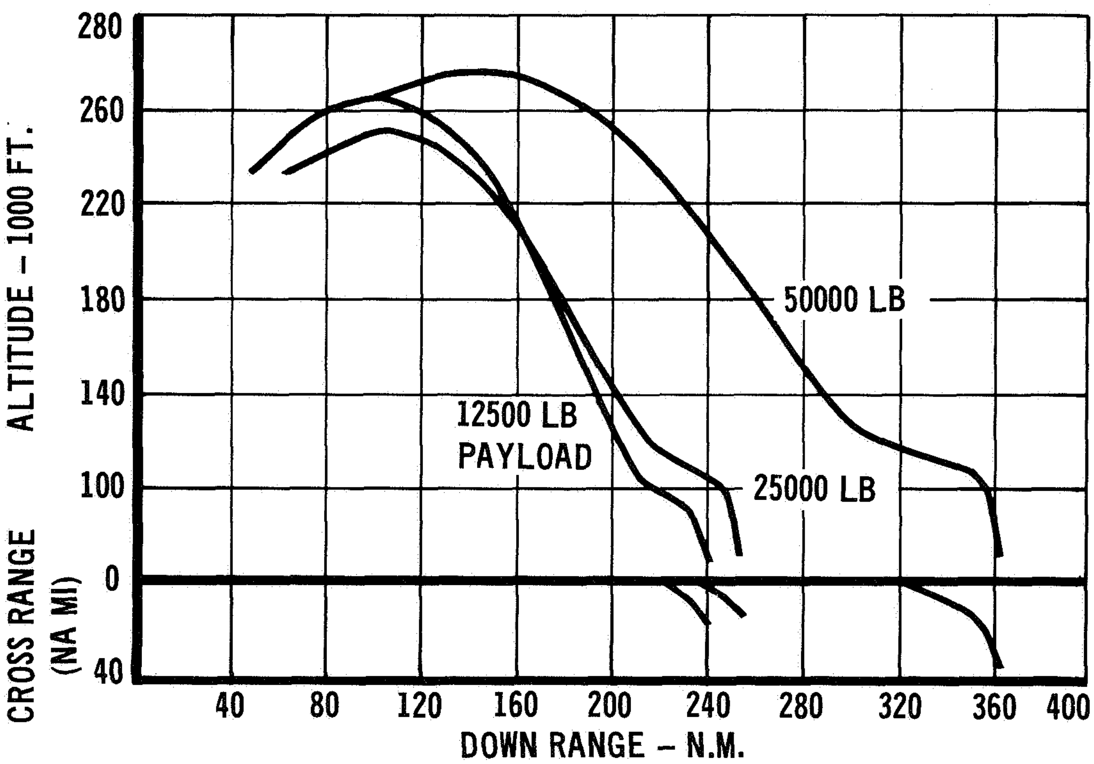


FIGURE 3-14

payload. Smaller payload configurations have slower separation speeds, hence shorter ranges. These ranges are consistant with the fuel allowed for the cruise, except that the lighter vehicles have a range capability of about 100 nautical miles greater than necessary.

A summary of the booster entry conditions is shown in Table 3-3 . This table shows range and peak dynamic pressure, q_{max}, together with initial entry conditions for each of the twelve cases considered. Payload is most important in determining the cruise back range. Lighter payload have shorter ranges as a result of their slower separation speeds and lighter weights. Some difference in range is apparent in the choice between liquid and solid zero stages. In general, the liquids require slightly greater cruise back ranges. In most cases, there is little variation in dynamic pressure due to the reusable versus expendable choice. The one exception exists in the case of the solid strap-on with a 12,500 lb. payload. This is apparently due to the difference of almost one degree in separation flight path angle. Little difference in peak dynamic pressure is experienced across the range of payloads investigated. This is due to the trade offs involved in velocity and flight path angle.

C. Orbiter Entry Analysis - In order to allow the sizing analyses to proceed independent of the aero/thermo analysis entry trajectories for the orbiter were determined on a parametric basis. This was accomplished by varying planform loading, W/S. Values of W/S equal to 48, 51 and 57 lbs/ft^2 were chosen to cover the payload range of interest.

In each case, two constraints were primarily responsible for the bank angle variation selected during orbiter entry. These were (1) that the temperature should not exceed 2200°F and (2) that the normal load factor should not exceed 3g's. Figure 3-15 is an example of how these constaints vary with velocity. Various regions are indicated as violating one or more of the constraints. Only the region below both curves gives satisfactory load factors and temperatures. A third constraint of lesser significance is also indicated. That is that bank angle should not exceed 90 degrees beyond 25,500 ft/sec. The bank angle limits shown apply only to the equilibrium glide portion of the reentry. The pullout portion which precedes it is generally more restricted in bank angle selection.

The only important aerodynamic forces involved in the orbiter entry performance are lift and drag. Coefficients of each of these variables as a

TABLE 3-3

BOOSTER ENTRY SUMMARY

PAYLOAD (LB)	TYPE OF STRAP-ON	ALTITUDE (FT)	VELOCITY (FT/SEC)	FLT.PATH ANGLE (DEG)	CRUISE RANGE (NM)	PEAK DYNAMIC PRESSURE (LB/FT)
50,000	SOLID – EXPENDABLE	263,762	8479	6.35	365	292
	SOLID – REUSABLE	258,917	8488	5.90	361	259
50,000	LIQUID – EXPENDABLE	266,742	8526	6.83	377	326
	LIQUID – REUSABLE	270,849	8523	7.17	378	341
25,000	SOLID – EXPENDABLE	233,354	6691	9.53	254	213
	SOLID – REUSABLE	236,157	6685	9.91	258	234
25,000	LIQUID – EXPENDABLE	241,465	6937	9.50	278	247
	LIQUID – REUSABLE	244,079	6932	9.84	278	268
12,500	SOLID – EXPENDABLE	230,331	5773	14.85	238	277
	SOLID – REUSABLE	235,297	5752	15.79	230	348
12,500	LIQUID – EXPENDABLE	231,483	6111	12.56	236	251
	LIQUID – REUSABLE	233,540	6105	12.89	238	264

REPRESENTATIVE BANK ANGLE CONSTRAINTS

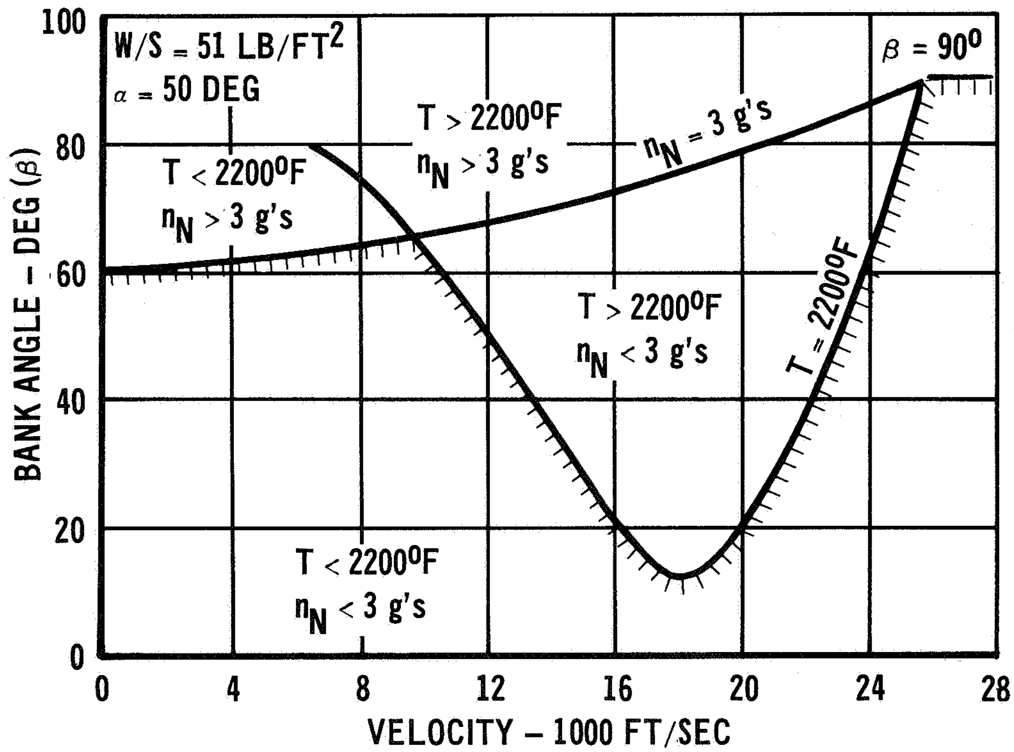


FIGURE 3-15

function of angle of attack are shown in Figure 3-16. These data were used in the analyses and were obtained from Reference 1.

High Angle of Attack Entry - High angle of attack entry trajectories were calculated for those planform loading conditions stated previously. In determining entry conditions de-orbit from a circular 270 nautical mile orbit was assumed. A retrograde impulse of about 435 ft/sec was applied resulting in an entry flight path of -1.5 degrees and a corresponding velocity of 25,990 ft/sec. Entry is defined as an altitude of 400,000 feet.

The trajectories were executed by commanding a 50 degree angle of attack throughout the flight regime and by commanding zero bank angle to pullout and a variable bank angle thereafter. Fifty degrees angle of attack was chosen as being near the highest possible value consistent with a 2200°F temperature constraints. The maximum lift coefficient, C_{Lmax}, occurs at 54 degrees but this was rejected as yielding too hot a trajectory.

After angle of attack was chosen to produce the minimum practical lift-to-drag ratio, bank angle in glide was then selected to satisfy the load and temperature constraints. Bank angle in pullout was arbitrarily chosen to be zero in order to eliminate possible heating problems in that phase of the trajectory. Figure 3-17 shows the resulting bank angle limitations for each of the W/S's considered. Note that the load factor constraint is independent of W/S. The figure also indicates that the temperature constraint cannot be met for the case of W/S = 57. In this instance the bank angle used in the trajectory calculation was chosen to be zero from 20,500 to 15,200 ft/sec. Subsequent thermodynamic analysis showed, however, that peak temperature was only 2250°F. The lower W/S finally selected yielded acceptable peak temperatures.

When an attempt was made to fly along these constraints it was found that below about 12,000 ft/sec an undesirably steep flight path angle resulted. For this reason a bank angle of 45 degrees was chosen for flight below 12,000 ft/sec. The resulting penalty in increased flight time is estimated to be less than 3%.

Figures 3-18 and 3-19 show significant parameters for a representative entry at high angle of attack.

Low Angle of Attack Entry - Low angle of attack entries were investigated for both maximum cross range and minimum time trajectories. Maximum time entries (unbanked flight) were omitted as being unrepresentative of likely missions. During glide the angle of attack was chosen to be 20 degrees. At

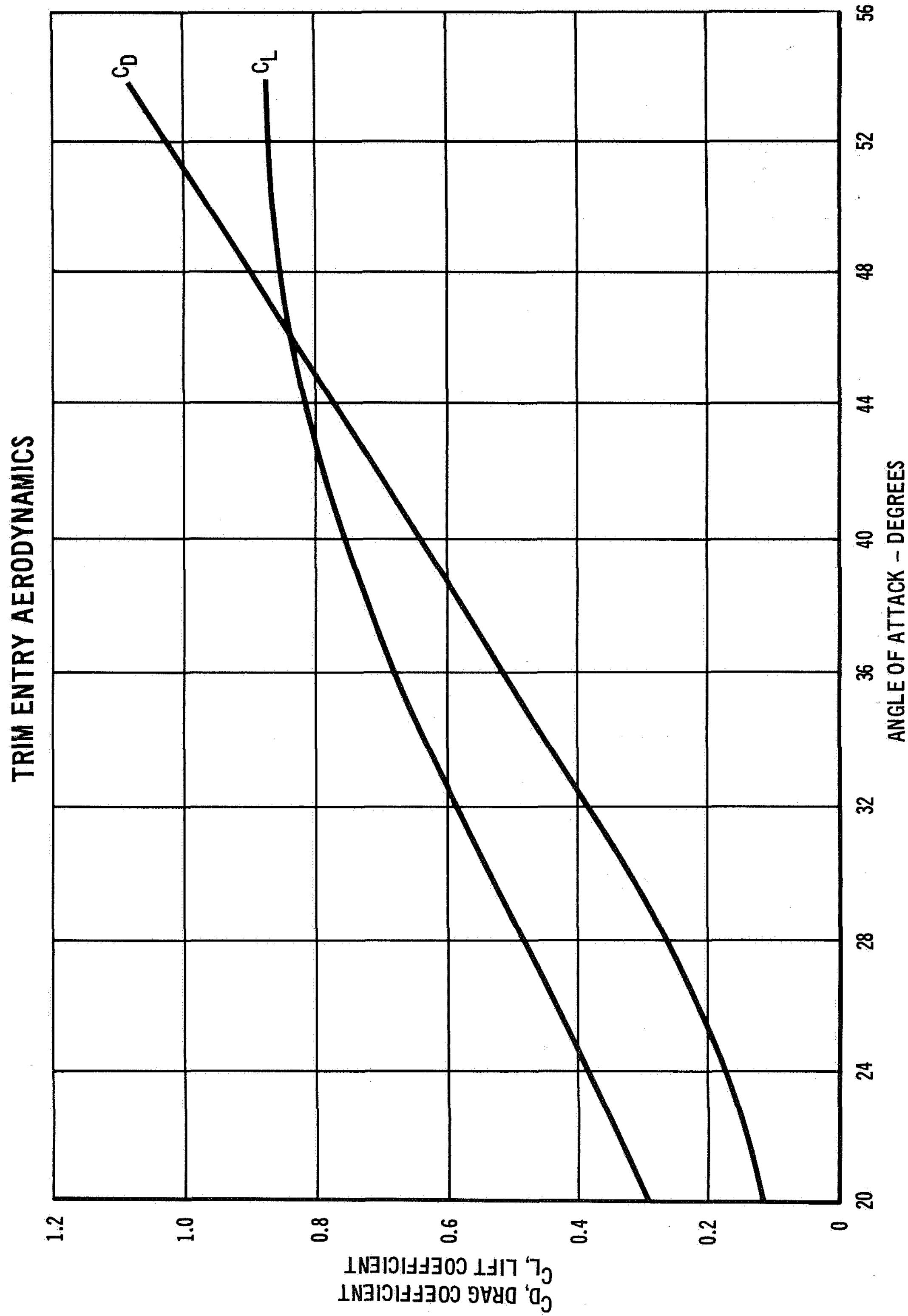

TRIM ENTRY AERODYNAMICS
C_D
C_L
ANGLE OF ATTACK – DEGREES
20
24
28
32
36
40
44
48
52
56
C_D, DRAG COEFFICIENT
C_L, LIFT COEFFICIENT
0
0.2
0.4
0.6
0.8
1.0
1.2

FIGURE 3-16

BANK ANGLE LIMITS FOR 2200° F
AND 3g CONSTRAINTS
α = 50 DEG

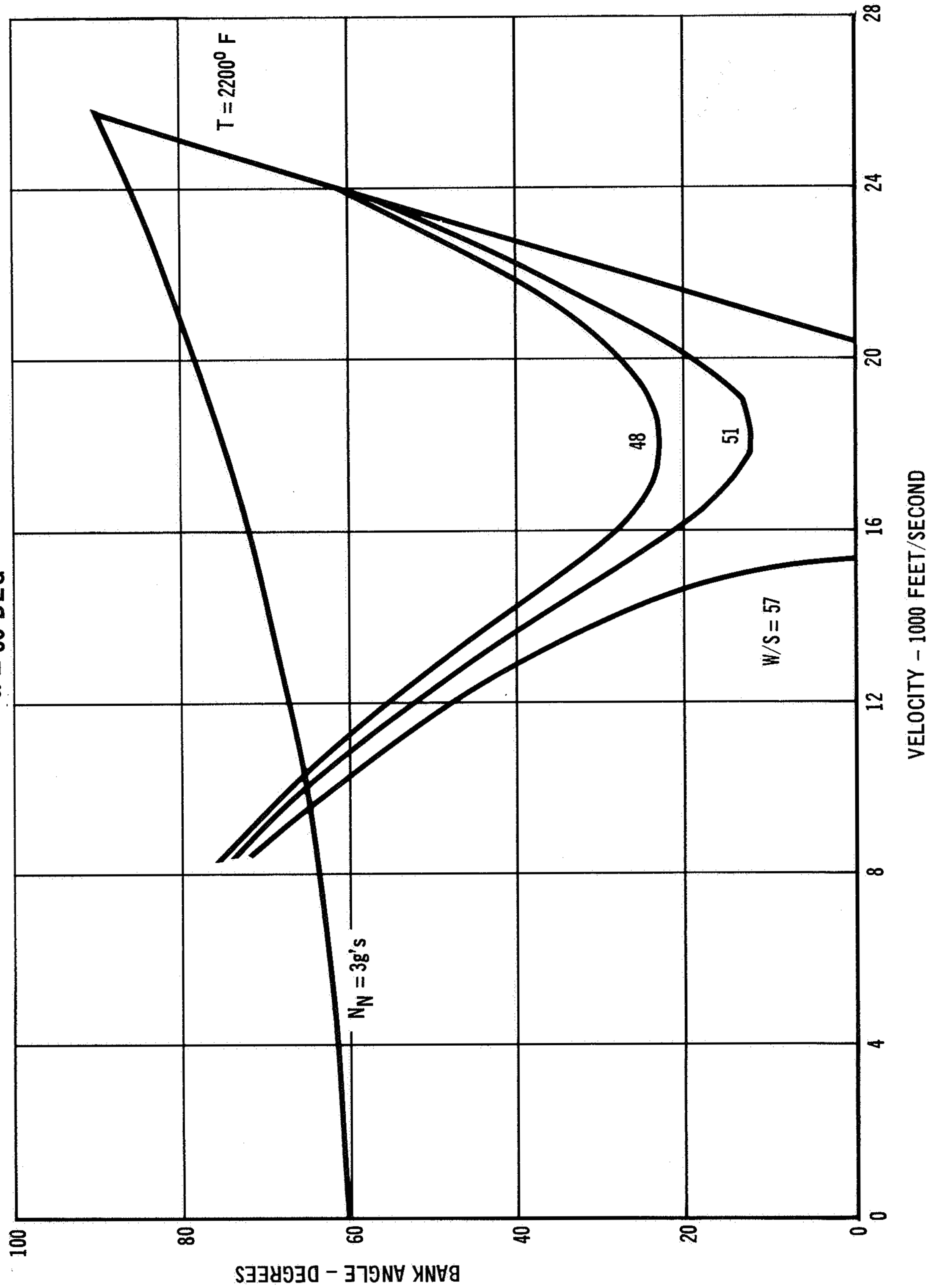


FIGURE 3-17

ORBITER ENTRY TRAJECTORY
PART I

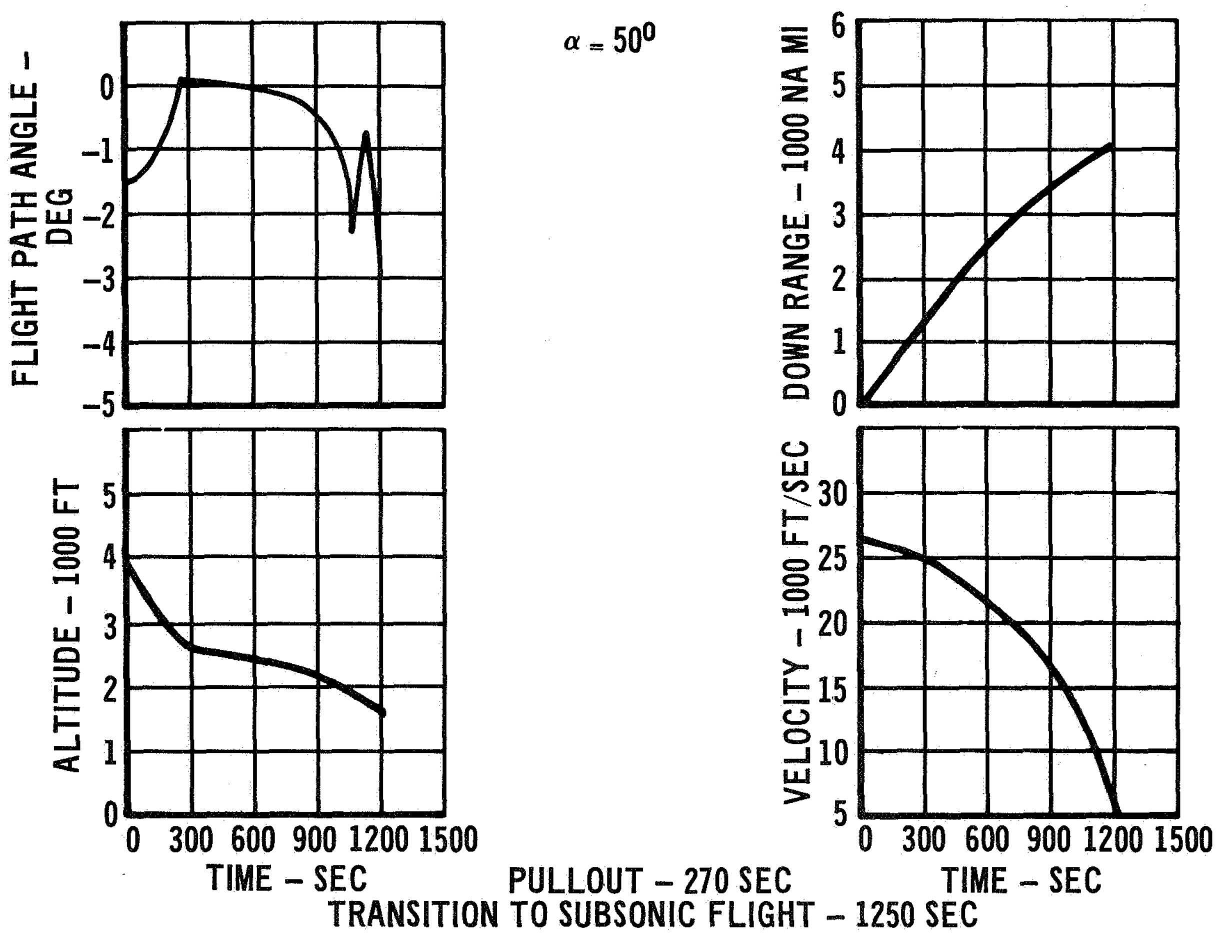
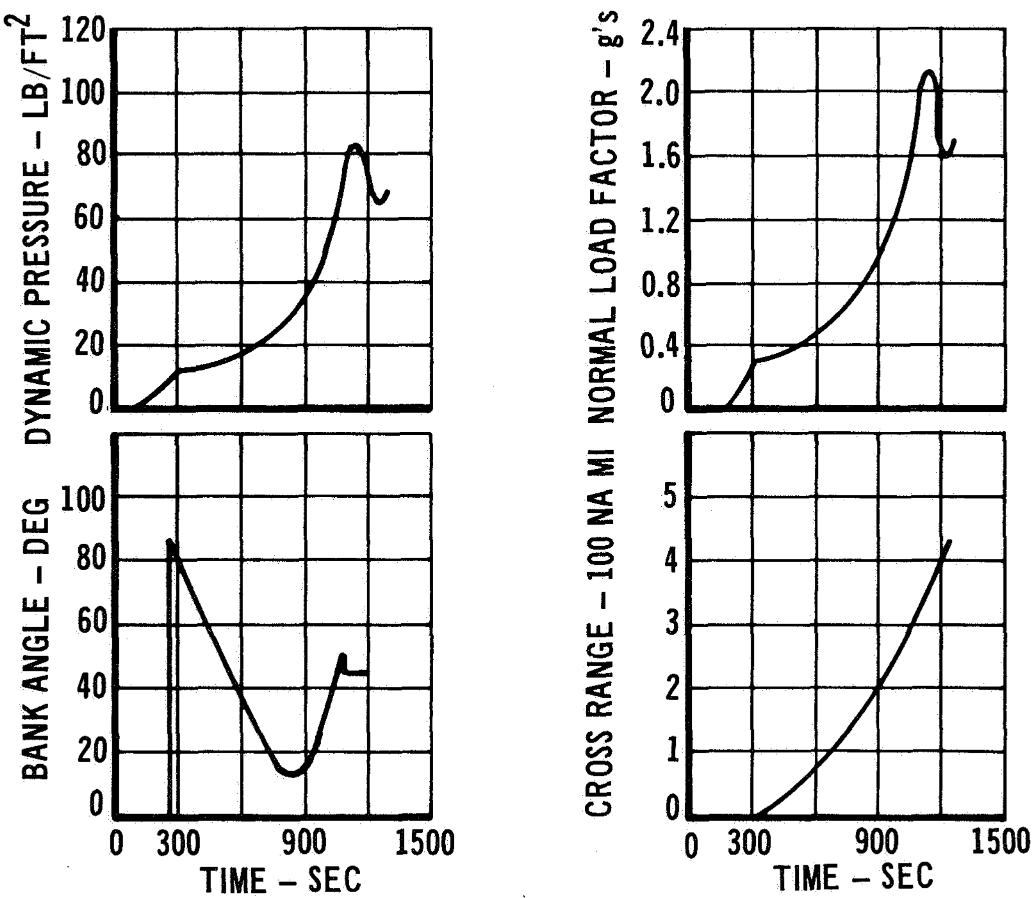


FIGURE 3-18

ORBITER ENTRY TRAJECTORY
PART II

$\alpha = 50^0$



PULLOUT – 270 SEC
TRANSITION TO SUBSONIC FLIGHT – 1250 SEC

FIGURE 3-19

angles lower than 20 degrees upper body heating becomes critical. Planform loading and entry conditions in this case were the same as those in the high angle of attack analysis.

During the analysis it was found that in order to prevent a skip phenomena from occuring it was necessary to perform the pullout maneuver at high angle of attack. Skip is defined as any increase in altitude after pullout. If bank angle is limited to 90 degrees, skip will occur if the pullout velocity is greater than the circular satellite velocity. Circular-satellite velocity is about 25,800 ft/sec for the altitudes of concern. Figure 3-20 shows pullout velocity as a function of the pullout angle of attack. From this, one can see that angles in the vicinity of 20 degrees are unacceptable and angles near 40 degrees are at best, marginal. Therefore, 50 degrees angle of attack was chosen for the pullout phase. Pullout velocity was not reduced by banking because of the likelihood of encountering a temperature problem.

Bank angle during glide was selected to either maximize cross range or minimize time subject to temperature and load factor constraints. Figure 3-21 presents these constraints for each of the planform loadings considered. For the minimum time cases these constraints were followed in order to minimize the vertical component of lift-to-drag ratio, (L/D). However, at speeds above 23,500 ft/sec, bank angle was modulated to damp oscillations. For maximum cross range entries these same bank angles were used at high speeds. The reason being to maximize the rate of change of heading angle which is proportional to the sine of the bank angle. The maximum cross range entries differ from the minimum time entries in that for maximum cross range the bank angle is ramped to zero at some optimum speed in order to increase (L/D) and stretch out the range to take advantage of the heading change acquired at high speeds. The optimum roll out speed was determined to be about 12,000 ft/sec.

With the above flight plan selections trajectories were calculated and performance determined. Figure 3-22 shows the resulting cross ranges and flight times. Note that even the minimum time cases give cross ranges in excess of 1900 nautical miles. This is more than any practical requirement. Thus, the minimum time type of entry was selected for the reference design.

Figures 3-23 and 3-24 show significant parameters for a representative orbiter entry at low angle of attack. The entry was executed as follows: from entry (400,000 ft.) to pullout (-.1° flight path angle) angle of attack was

SKIP BOUNDARIES

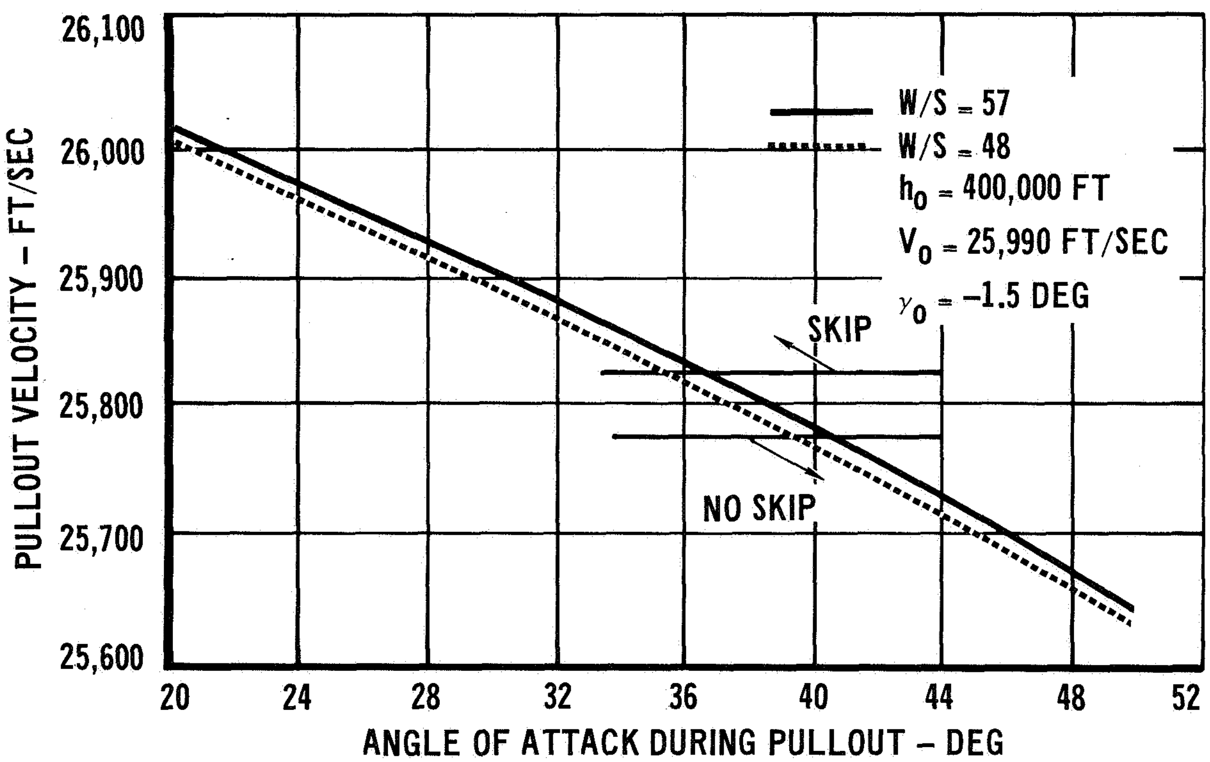


FIGURE 3-20

BANK ANGLE LIMITS FOR 2200 °F
AND 3g CONSTRAINTS
α = 20 DEG

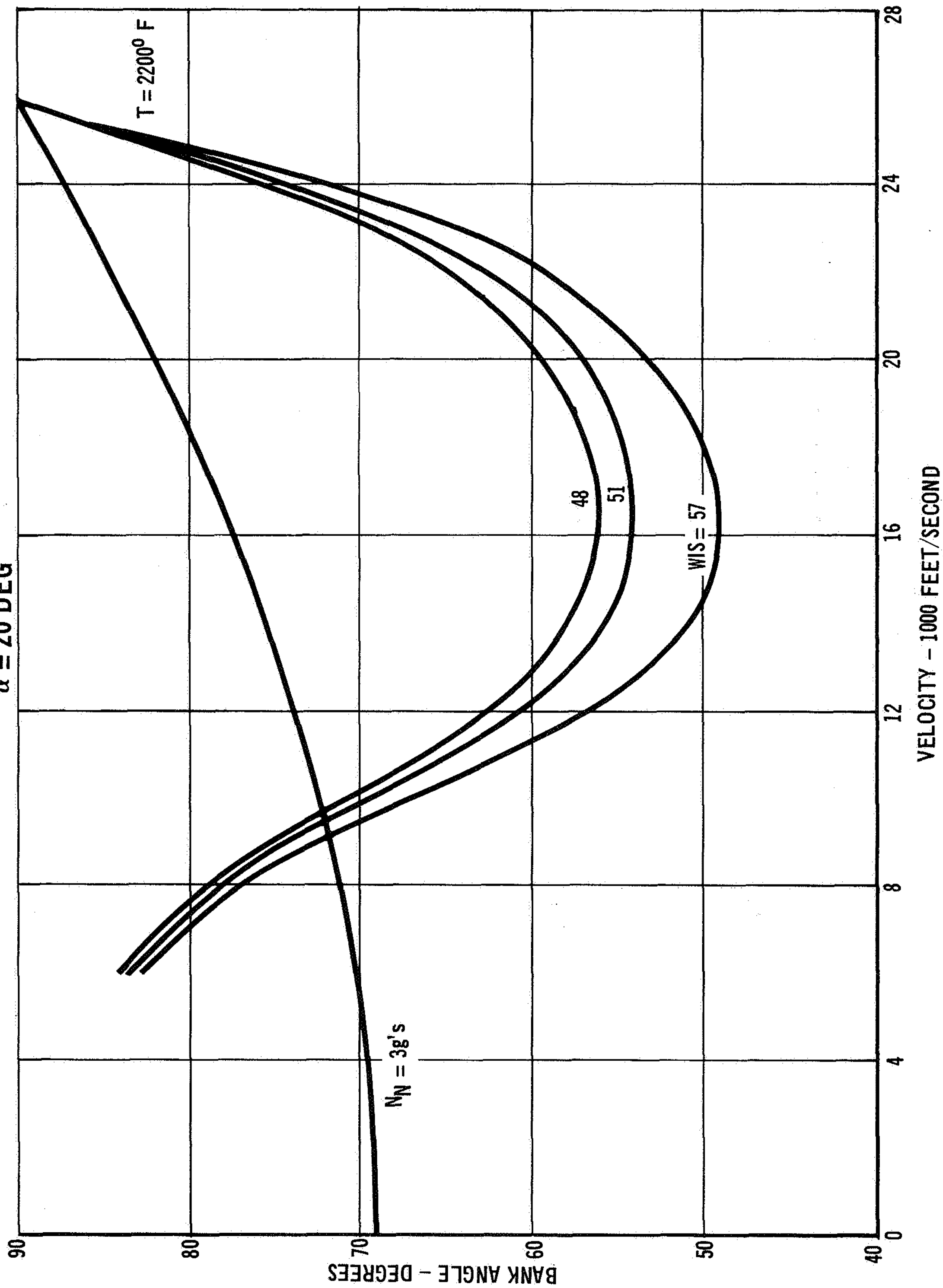


FIGURE 3-21

ORBITER CROSS RANGE CAPABILITY

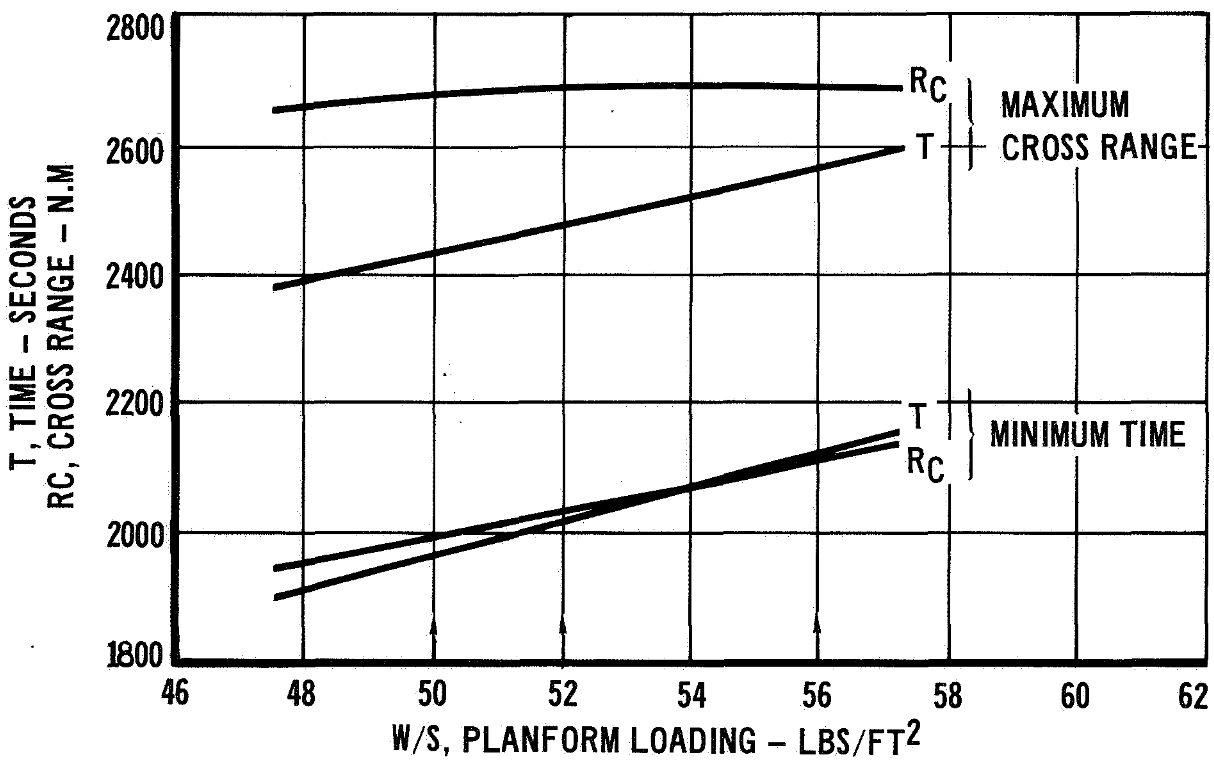
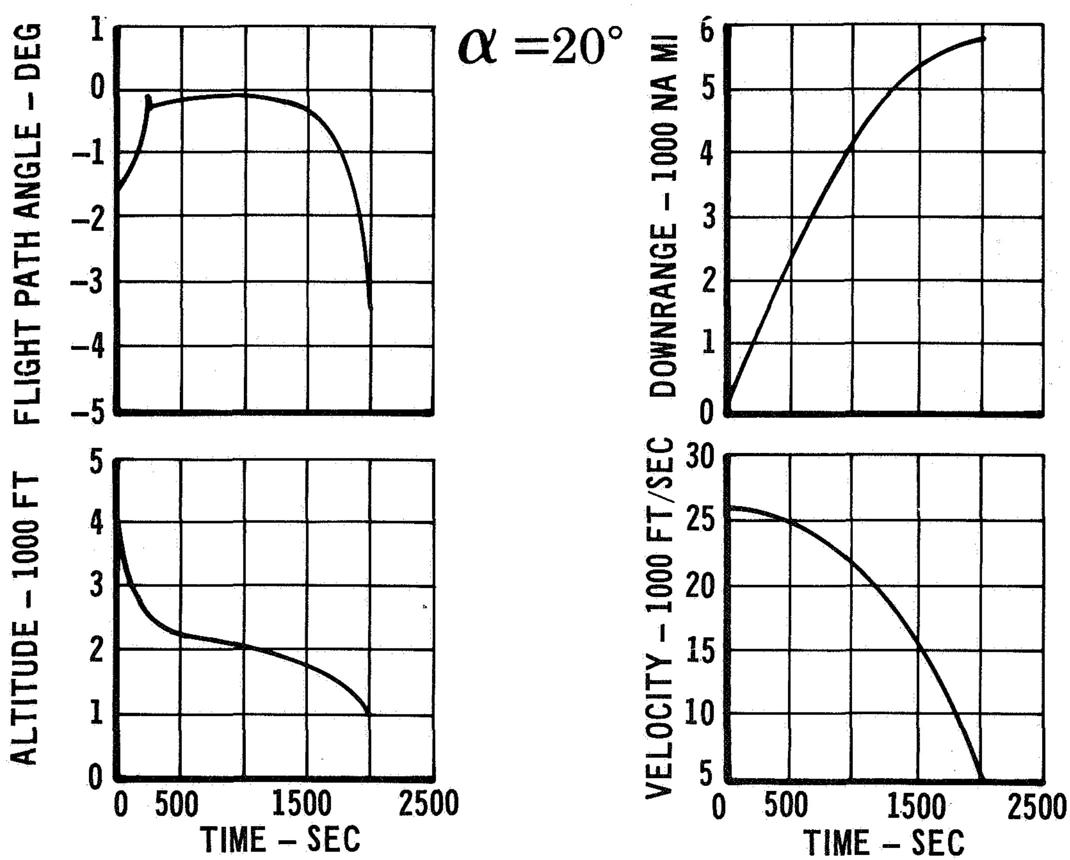


FIGURE 3-22

ORBITER ENTRY TRAJECTORY
PART I

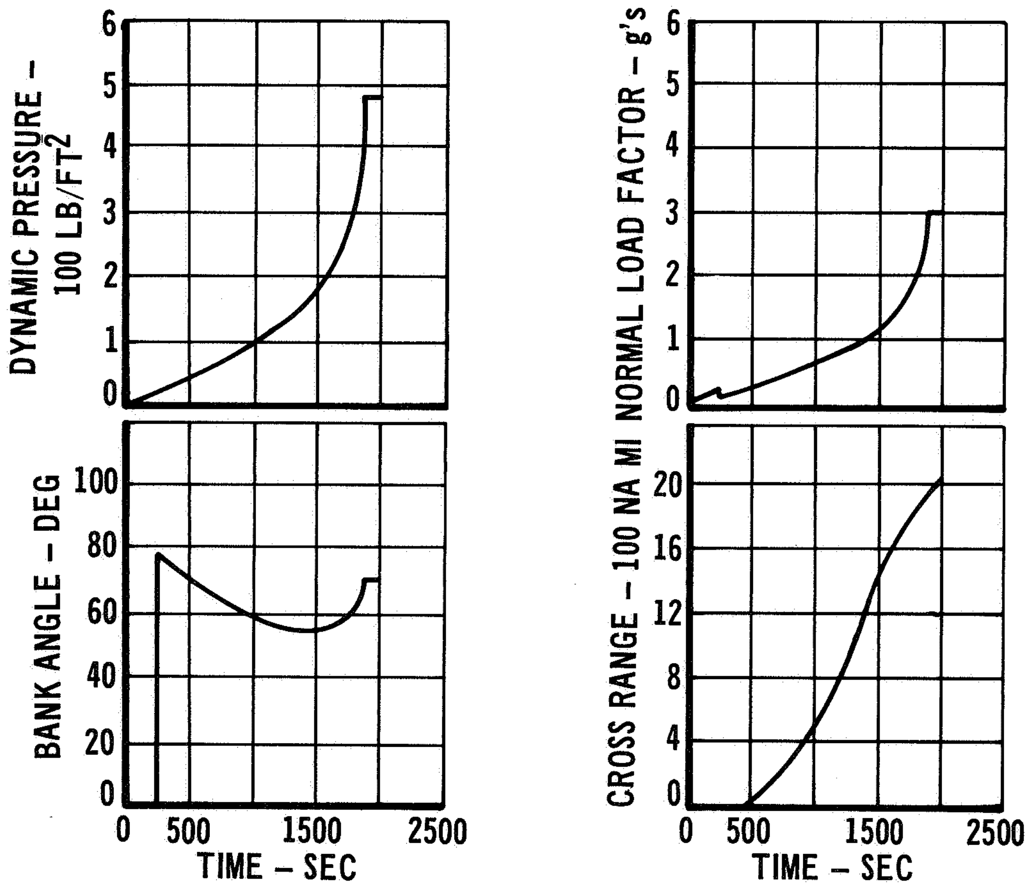


PULLOUT – 270 SEC
TRANSITION TO SUBSONIC FLIGHT – 2000 SEC

FIGURE 3-23

ORBITER ENTRY TRAJECTORY
PART II

$\alpha = 20°$



PULLOUT – 270 SEC
TRANSITION TO SUBSONIC FLIGHT – 2000 SEC

FIGURE 3-24

50 degrees and bank angle was zero. After pullout, angle of attack was kept at 20 degrees. Bank angle was modulated to drop to a 2200°F temperature boundary and then fly along it. At about 1880 seconds the vehicle experienced a normal load factor of 3g's. The temperature boundary was then left and the more restrictive load factor boundary was followed. The trajectory was terminated at 5000 ft/sec where the vehicle would normally begin the transition to subsonic flight.

Orbiter Entry Summary - Figure 3-25 compares altitude-velocity profiles for high and low angle of attack entries. A planform loading, W/S, of 51 was selected as being representative. Different values of W/S would produce the same altitude velocity profile by means of different bank angle histories. The flight times would also be different. The approximate 2200°F isotherms included in the figure demonstrate how the trajectories were shaped and show that the temperature constraint can be met. In some instances (particularly at low angle of attack) even lower peak temperatures are possible but only at the expense of increased flight time and subsequently increased total heat.

Figure 3-26 shows altitude, down range and cross range for the same two trajectories. It is worth noting that even the high angle of attack case exceeds 400 nautical miles of cross range which is more than enough for once-a-day return capability. The low angle of attack case has a cross range of 2000 nautical miles.

Table 3-4 summarizes cross ranges and times for each of 9 entries. A considerable amount of mission flexibility is indicated. Cross range can be as high as almost 2700 nautical miles with a corresponding flight time of 2600 seconds. If less than 400 nautical miles of cross range is needed, flight time can be reduced to about 1300 seconds. With the exception of the heaviest vehicle at high angle of attack all cases experience a peak temperature of 2200°F. If the heaviest vehicle is lightened to a W/S of 56, it too will experience only 2200°F.

D. Thermodynamic Analysis - One of the ground rules established for this study was that the Thermal Protection System (TPS) for the Concept "S" core vehicle configurations be identical to the TPS developed for the orbiter in the SAMSO-STS study. However, different flight trajectories were necessitated for this study because of changes in orbit altitude, payload weight and propulsion requirements. Thus the purpose of the thermodynamic analyses in this study was

ORBITER ENTRY ALTITUDE/ VELOCITY PROFILES

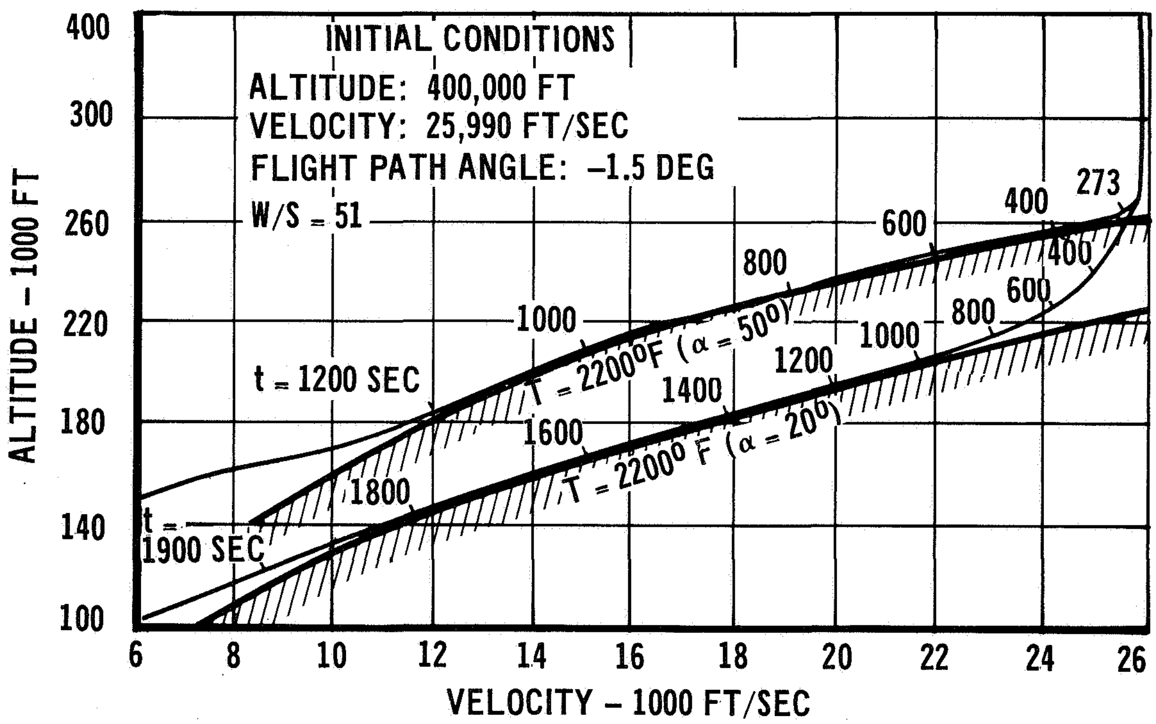


FIGURE 3-25

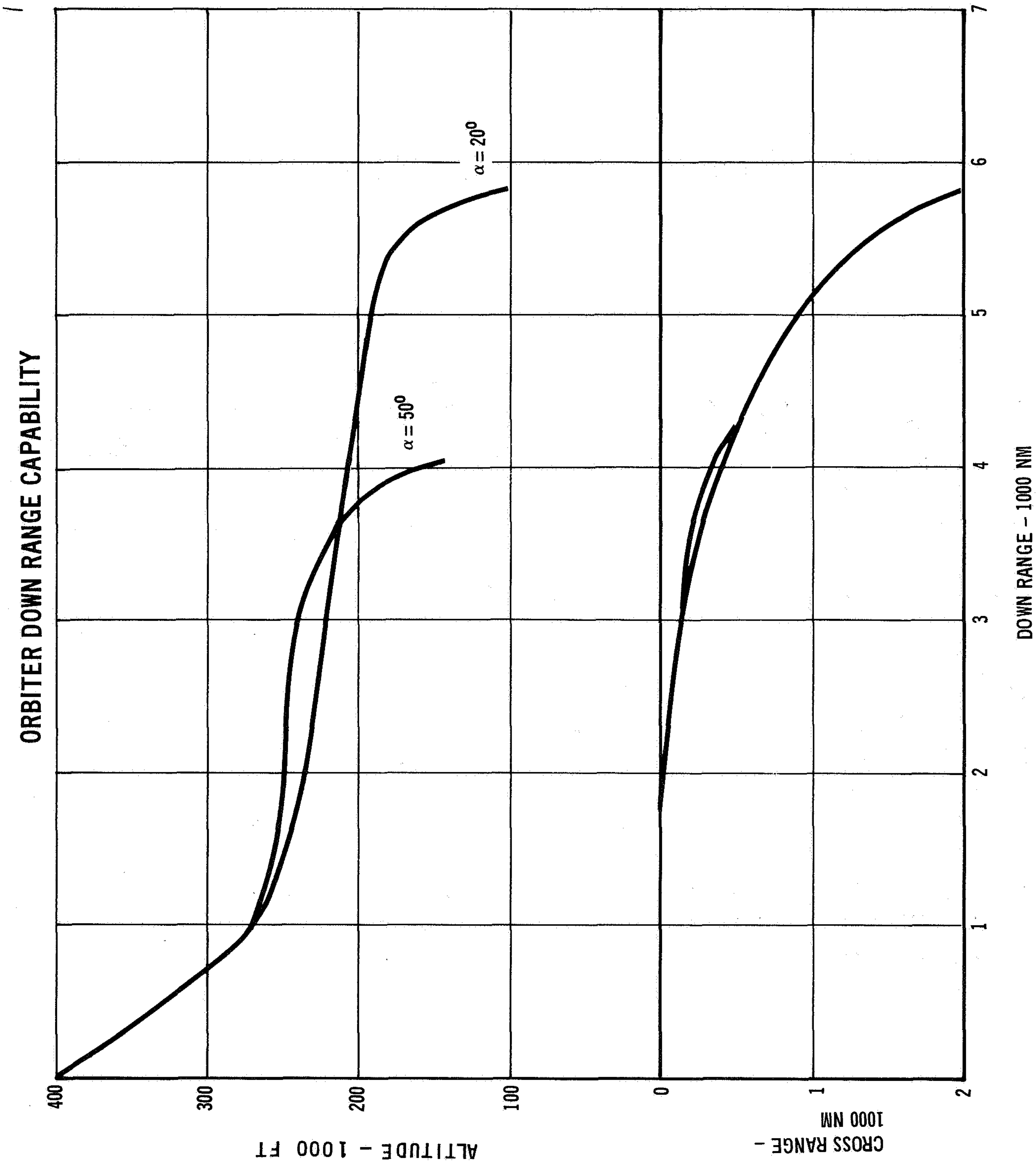

ORBITER DOWN RANGE CAPABILITY
α = 20°
α = 50°
DOWN RANGE – 1000 NM
1
2
3
4
5
6
7
ALTITUDE – 1000 FT
400
300
200
100
0
CROSS RANGE – 1000 NM
1
2

FIGURE 3-26

TABLE 3-4

ORBITER ENTRY SUMMARY

PAYLOAD (LB)	PLANFORM LOADING, W/S (LB/FT^2)	TYPE OF REENTRY	CROSS RANGE (NM)	FLIGHT TIME (SEC)
50,000	57	*HIGH α; MINIMUM TIME	405	1329
25,000	51	*HIGH α; MINIMUM TIME	498	1252
12,500	48	*HIGH α; MINIMUM TIME	526	1210
50,000	57	*LOW α; MINIMUM TIME	2137	2158
25,000	51	*LOW α; MINIMUM TIME	2018	1997
12,500	48	*LOW α; MINIMUM TIME	1942	1913
50,000	57	LOW α; MAXIMUM CROSS RANGE	2692	2597
25,000	51	LOW α; MAXIMUM CROSS RANGE	2686	2456
12,500	48	LOW α; MAXIMUM CROSS RANGE	2658	2382

*DESIGN TRAJECTORIES

to (1) define the thermal boundaries which serve as a constraint in the trajectory shaping analyses and (2) through detail, thermal analysis of the critical trajectories ensure that the TPS limits are not violated.

Initially, thermal boundaries for a 2200°F bottom surface temperature for entry at angles of attack of 20° and 50° were constructed. The 2200°F isotherm is a function of altitude, velocity, angle of attack and vehicle length. These parameters served as constraints in developing the orbiter and booster entry trajectories. The resulting trajectories were analyzed to ascertain that the peak temperatures everywhere on the vehicle surface did not violate the TPS capabilities and also that the internal temperatures, which are influenced strongly by heating duration, are within the acceptable limits.

<u>Orbiter Entry Heating</u> - Orbiter entry trajectories for low (α=20°) and high (α = 50°) angle of attack and for each of three payload weights were defined in Section C. However, only the entries with the highest payload weight (50,000 lb) were investigated since these entries result in higher temperatures. Figures 3-27 and 3-28 present the heat flux and surface temperature histories expected on the orbiter bottom surface center line, 30 feet aft of the nose cap. The corresponding curves from the SAMSO-STS study which sized the TPS are also included for comparison. The SAMSO-STS peak temperature profiles are about 200°F cooler than the 2200°F Concept "S" values but the heating duration is longer. Peak surface temperatures at various points on the Concept "S" orbiter are depicted in Figure 3-29. The Concept "S" peak temperatures are within the 2200°F service temperature of TD nickel chrome. However, a 10% weight savings in insulation can be achieved if the TPS is designed to the shorter Concept "S" entries.

Note in Figure 3-28 the close similarity of peak surface temperatures, even though the angle of attack of the two Concept "S" trajectories vary between 20° and 50°. This is due to the compensating effect angle of attack has on heating rate for a lifting body. In general, the higher angle of attack will increase the heat transfer rate but it will also increase the lift coefficient. Thus the vehicle will decelerate at a higher altitude where lower heating rates prevail. Often, boundary layer transition or cross flow effects, parameters which depend on angle of attack, can alter this conclusion.

Prediction of the laminar and turbulent heating rates are based on a simplified numerical correlation of results computed by Hank's Rho-Mu method. The

ORBITER HEATING RATE HISTORIES

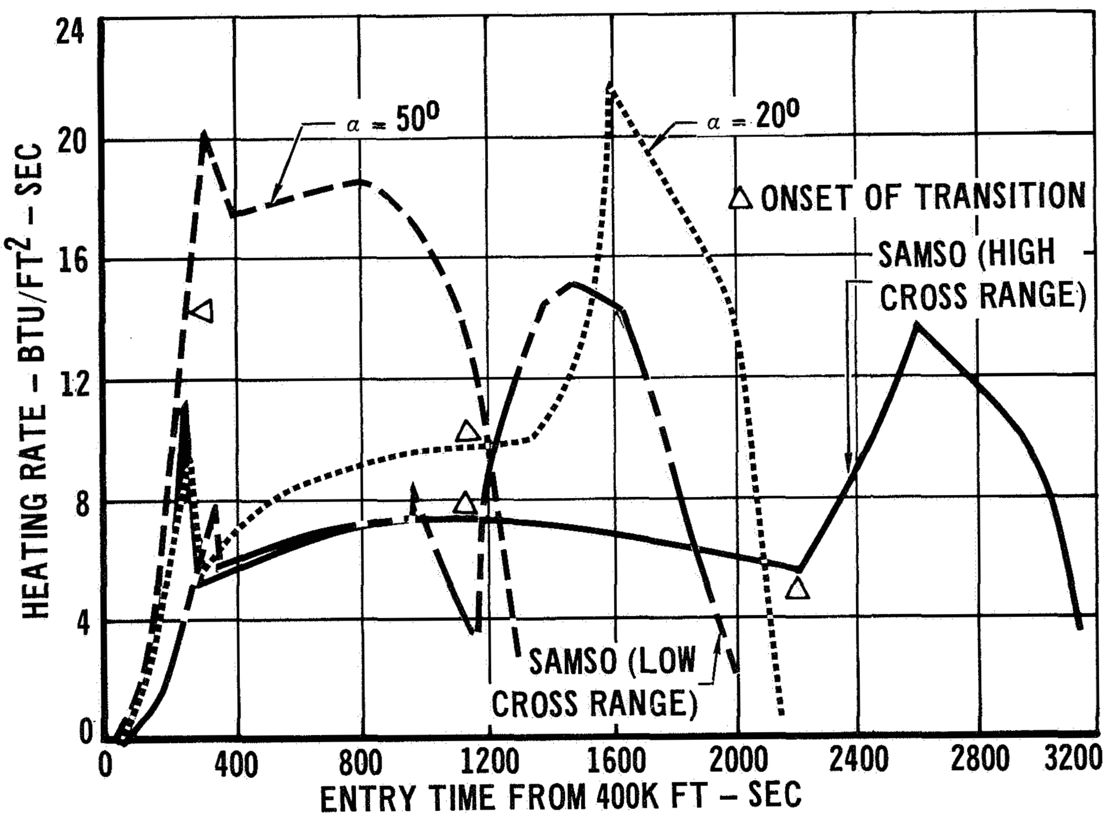


FIGURE 3-27

ORBITER ENTRY TEMPERATURE HISTORIES

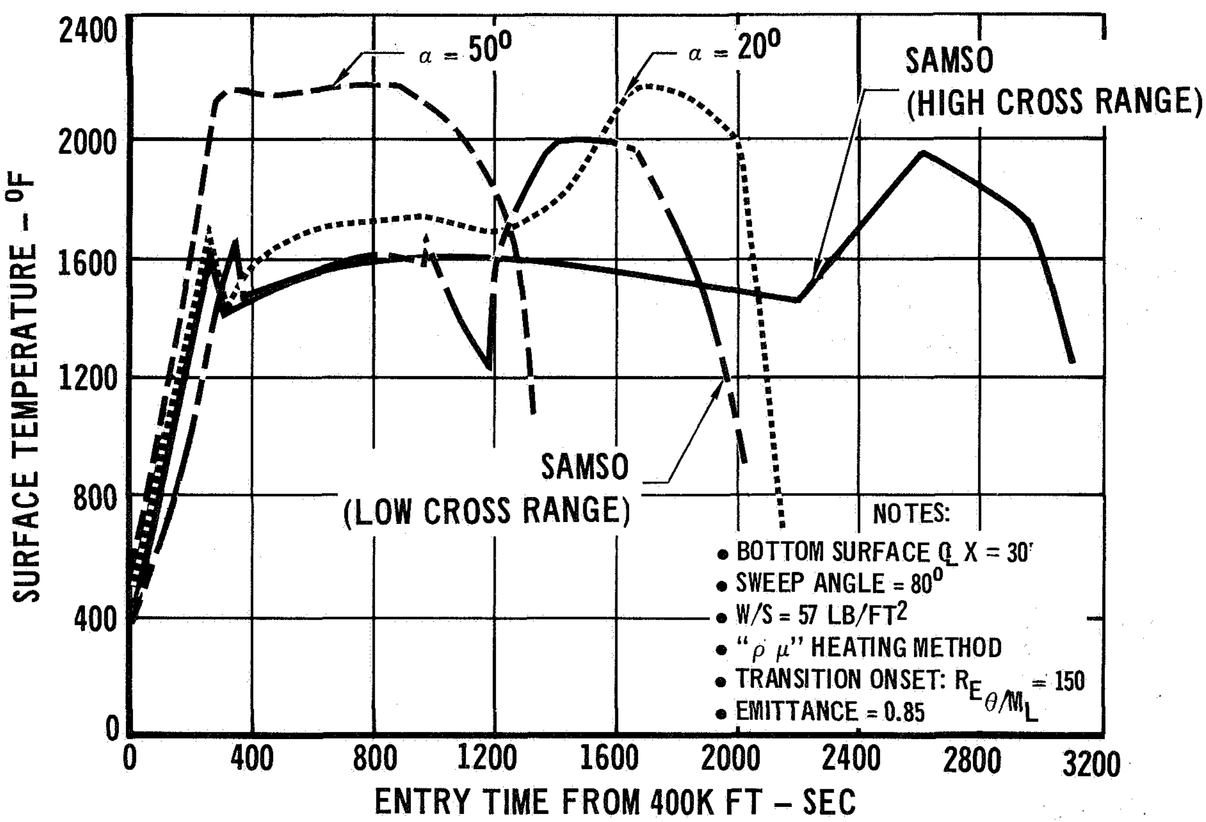


FIGURE 3-28

MAXIMUM ENTRY TEMPERATURES
Center Line Temperatures

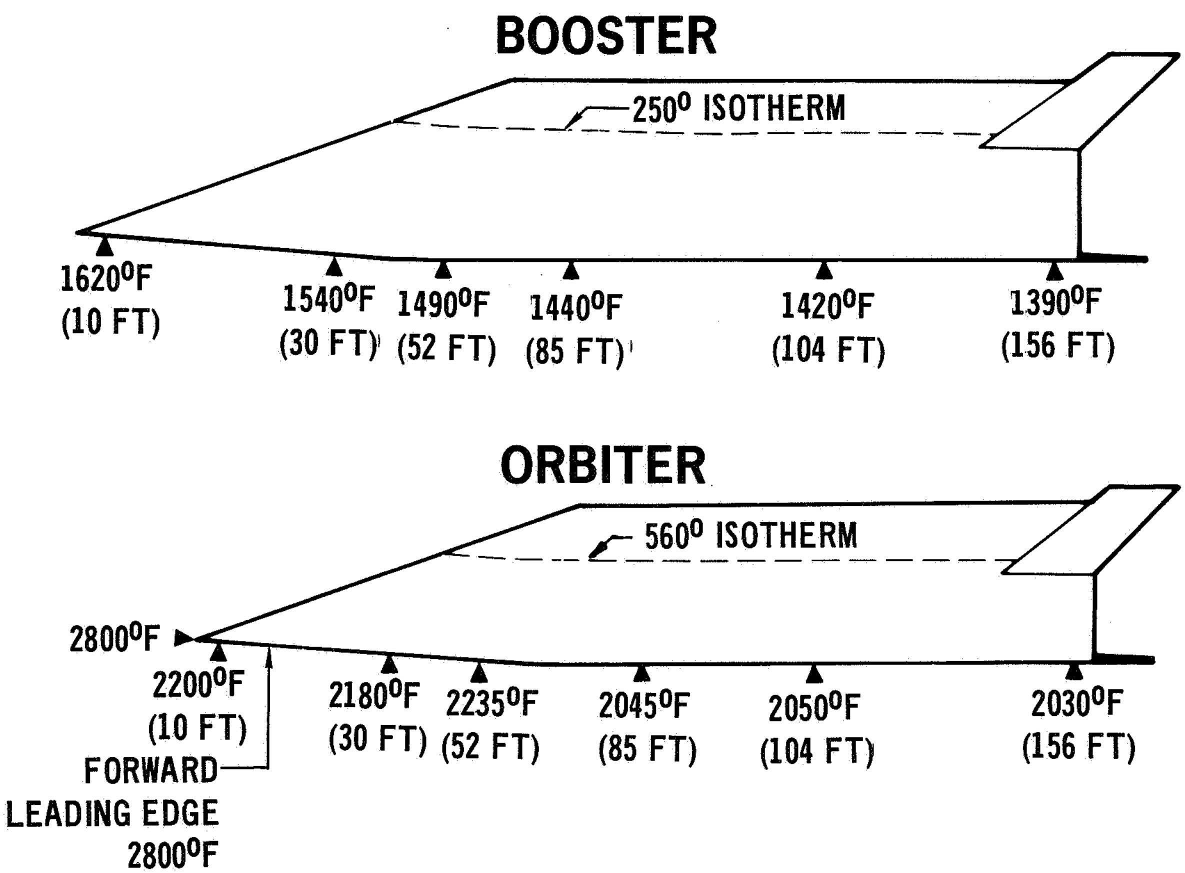


FIGURE 3-29

Rho-Mu theory yields the best correlation of turbulent flight data and compares favorable with other methods for estimating laminar heating rates. Cross flow effects, which cause a higher heating rate with increasing angle of attack, was also factored in the analysis. Transition of the laminar boundary layer is assumed to initiate at a ratio of momentum Reynolds number to local Mach number (Re_θ/M_L) of 150 and become fully turbulent at Re_θ/M_L of 212. Transitional heating during the interim increases from laminar to fully turbulent heating in direct proportion to Re_θ/M_L. It is well known that any method of predicting transition has a high degree of uncertainty. As shown in Figure 3-30 the increase in temperature due to transition uncertainty is not overly severe as indicated by comparing the temperatures predicted by two different transition criteria.

Booster Entry Heating - In this study the assumption was made that the booster and orbiter have idential thermal protection systems. This assumption permits the interchange of functions between vehicles, but it imposes a weight penalty on the booster TPS. Since the booster does not attain orbital velocity, the booster entry temperatures are less severe and of shorter duration than the orbiter entry temperatures. A typical booster temperature profile is presented in Figure 3-31 whereas the peak entry temperatures over the booster surface are depicted in Figure 3-29. It is estimated that the booster TPS can be reduced by 4200 lb if the TPS is designed to withstand only the booster environment.

Launch Heating - A three to tenfold increase in launch heating can occur in the cavity region formed when the booster and orbiter are mated belly to belly in the launch position. However, the resulting launch temperatures in this critical area will be much less than those experienced on the bottom surface during entry and thus no temperature problems are expected during launch.

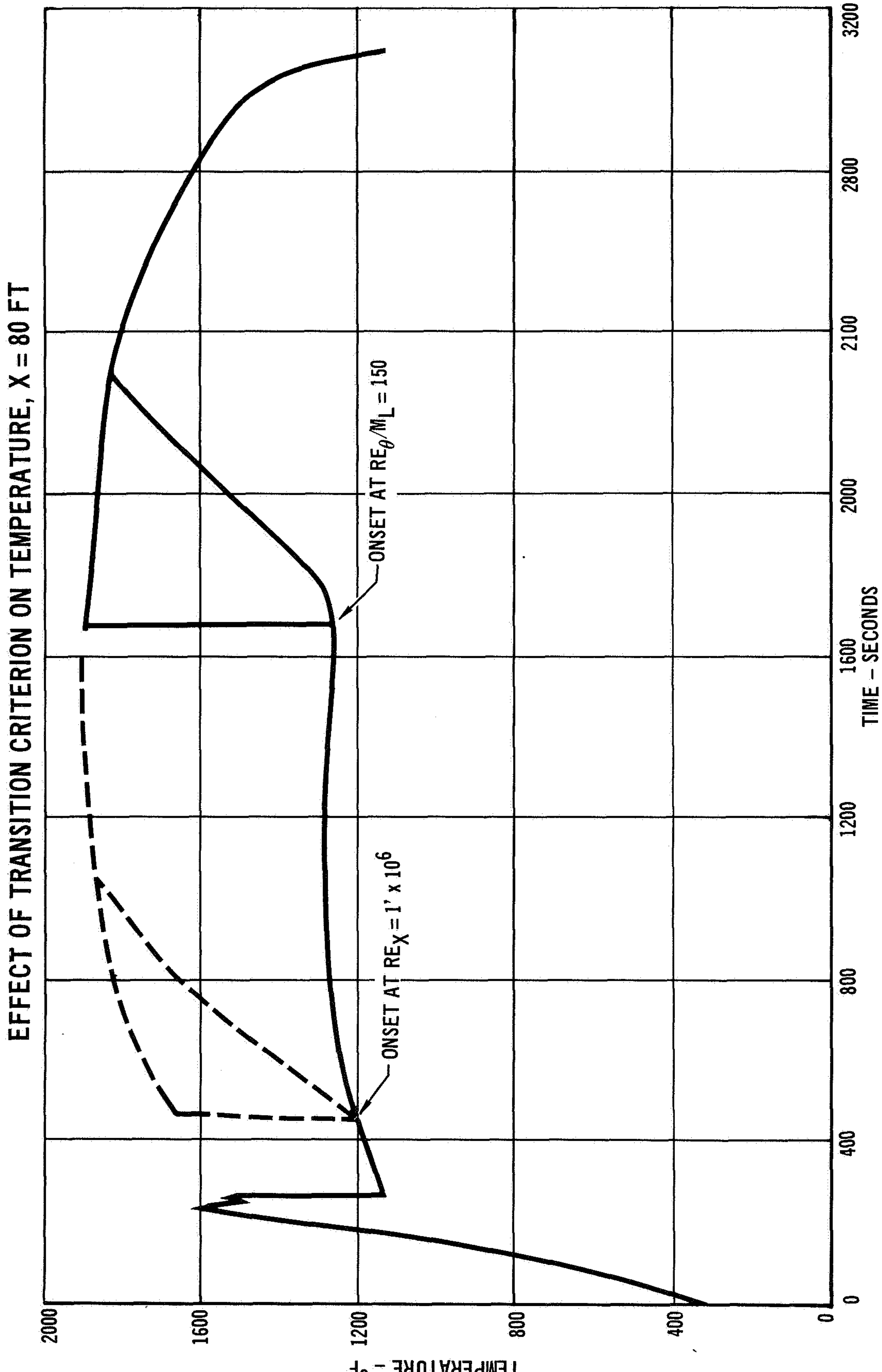

EFFECT OF TRANSITION CRITERION ON TEMPERATURE, X = 80 FT
ONSET AT $RE_{\theta}/M_L = 150$
ONSET AT $RE_X = 1' \times 10^6$
TIME – SECONDS
0
400
800
1200
1600
2000
2100
2800
3200
TEMPERATURE – °F
0
400
800
1200
1600
2000

FIGURE 3-30

BOOSTER ENTRY TEMPERATURE HISTORIES

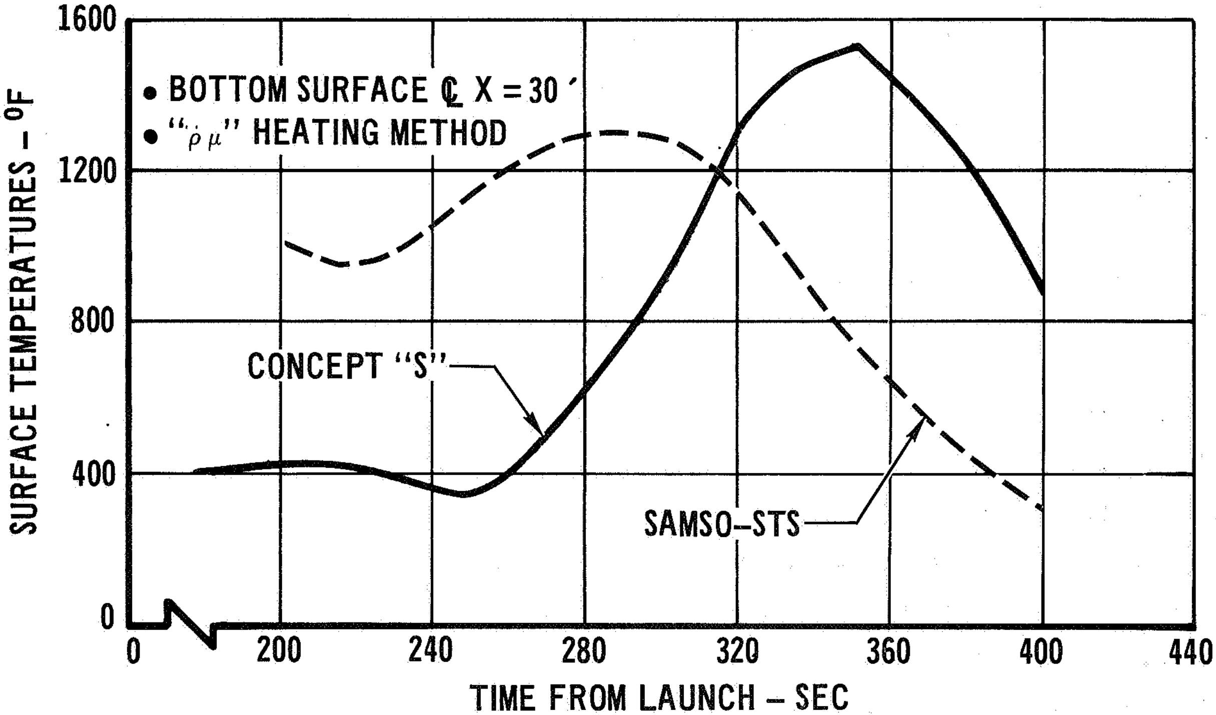


FIGURE 3-31

3.1.2.3 Propulsion Sizing Analysis - The propulsion sizing study was conducted in three phases. The first phase was concerned with developing basic sizing ground rules and data for subsequent generation of baseline zero stage sizes. The second phase was conducted to demonstrate the effect of various sizing options on the concept and to select a baseline system. The third phase was generation of baseline zero stage designs. In addition, the baseline data was extrapolated to produce approximate sizing data for other options.

A. Stage Sizing Analysis - In order to effect a reasonable design of the various propulsion systems (i.e. core stage and zero strap-ons) required for the siamese concept certain basic sizing ground rules and data had to be established. In the case of the propulsion systems for the core vehicles basic characteristic data was obtained from the results of the SAMSO STS study, Reference 1. The NASA provided the basic characteristic data for sizing both the solid and liquid zero stage strap-ons.

Core Stage Evaluation - In sizing the core vehicles propulsion systems several design decisions were required involving scaling procedures for varying payload and performance characteristics. Specifically these included definition of the degree of orbiter/booster stage commonality, payload envelope and core stage scaling with payload.

Since one of the objectives of the current space shuttle programs is to achieve a major reduction in orbital payload delivery cost it was decided to ground rule a maximum of commonality between orbiter and booster stages. The implication of this ground rule to the propulsion systems is that they be completely interchangeable. In brief, these systems include an attitude control system, an air breathing booster cruise back and orbiter landing assist system and a boost propulsion system for launch and orbit insertion. Further description of these systems can be found in Section 3.1.5 of this report.

No obvious problem exists in making the attitude control system common between the two stages.

There is some commonality penalty in propellant tankage for the JP-4 fuel of the air breathing system. Since the landing weight of both core stages is quite similar the engines are equally adaptable to either stage. The booster cruise back condition however, requires approximately eight times the orbiter landing assistant propellant. The tankage penalty was considered acceptable if the orbiter stage tanks were off loaded to the appropriate landing assist JP-4 fuel weight values.

Another commonality decision requiring resolution concerned the utilization of the empty booster payload bay. Leaving the payload bay empty represents an obvious mass fraction compromise. Extending the short boost system propellant tank forward through the aft payload bay bulkhead for an integral stage tank design destroys stage system commonality. The best solution found to preserve commonality was to size drop-in tanks for the empty booster payload bay. This resulted in a loaded booster weight which was greater than the orbiter.

If common engines are used the stage thrust-to-weight ratio is reduced contributing to higher boost losses. The thrust-to-weight ratio shift is not large however, and the effects were felt to be acceptable. Consequently, the drop-in tank was selected for the booster stage payload bay to maximize booster/orbiter commonality and the slightly higher losses accepted in the interest of utilizing common boost engines.

The sizing objective included definition of orbiter vehicles for 12,500, 25,000 and 50,000 pound payloads. Several options exist for definition of payload envelope. These include variable density, length, diameter and length-to-diameter ratio. The outer mold lines of the core stages and conversely its mass fractions are strongly affected by the payload bay dimensions. Within limits, the stage propellant mass fraction would be maximized by a high density payload with a fixed length-to-diameter ratio. Considering the intended flexibility of the shuttle concept, however, it is unlikely that the payloads could be controlled in this manner. The orbiter model for this study was designed for a 50,000 pound payload with a 15 ft diameter and 60 ft length envelope. Other shuttle studies have specified a minimum payload diameter of 15 ft. Since the SAMSO STS orbiter model was already at this minimum; the 15 ft diameter was retained with a variable length established by the density corresponding to 50,000 lb. in a 60 ft length. This density was 4.72 lb/ft^3.

The remaining question requiring resolution concerned the manner of varying the core stage characteristics with payload. The obvious choice was to retain the design parameters of the model. This is grossly identified by fixing the stage thrust-to-weight ratio and characteristic velocity and scaling the stage around the shorter payload lengths by mass and length relations. Another option was to simply place smaller payloads into the 50,000 lb payload stage. The subsystem designs generated for the model orbiter would remain essentially unchanged allowing maximum utilization of the SAMSO STS studies results. With this option the thrust-to-weight ration and characteristic velocity change with payload. Since this option has unused orbiter payload bay volume at the lower payloads, orbiter drop-in tanks can be added to maximize the core stage propellant loading.

It would be equally appropriate to select any other combination of characteristics within the scope of this problem. If the thrust-to-weight ratio is maintained within the range of the model orbiter, arbitrarily fixing its value is not detrimental. Orbiter characteristic velocity, however, has a major influence on the core vehicle size as demonstrated in Figure 3-32. The outer mold lines of the lifting body are defined by the volume of the propellant required and by the payload bay envelope. Since the vehicles mold lines reflect the structure and propellant tanks configuration the characteristic velocity stage performance is directly related to stage length and payload. This figure shows the data generated by scaling the model parameters. The discrete points as indicated represent the fixed orbiter/variable payload option with orbiter drop-in tanks in the unused payload bay volume. Note the effect of the orbiter drop-in tanks in improving the characteristic velocity of a fixed length orbiter as payload is decreased. This infers that the propellant mass fraction is improved as would be expected.

Figure 3-33 demonstrates that the core vehicle mass fraction also improves with stage length. This is a result of constantly improving volumetric efficiency with length. Since propellant mass fraction is an index of the stage performance efficiency, maximum core stage length tends toward maximized core stage performance.

The previous data reflects the addition of two structural increments to the basic core stage. These were appropriately sized drop-in tanks in the core stages and a propellant transfer system to allow parallel burn of all core stage engine at lift off without depletion of orbiter propellant. Figure 3-34 defines the drop-in-tanks sized for the payload bays. All the design features of the core stage boost tanks are retained. The same insulation system was used as defined by Section A-A. The insulation system has a specified weight of .373 lb/ft^3. The tanks are all 15 ft in diameter with variable lengths ranging

EFFECT OF CHARACTERISTIC VELOCITY ON ORBITER LENGTH

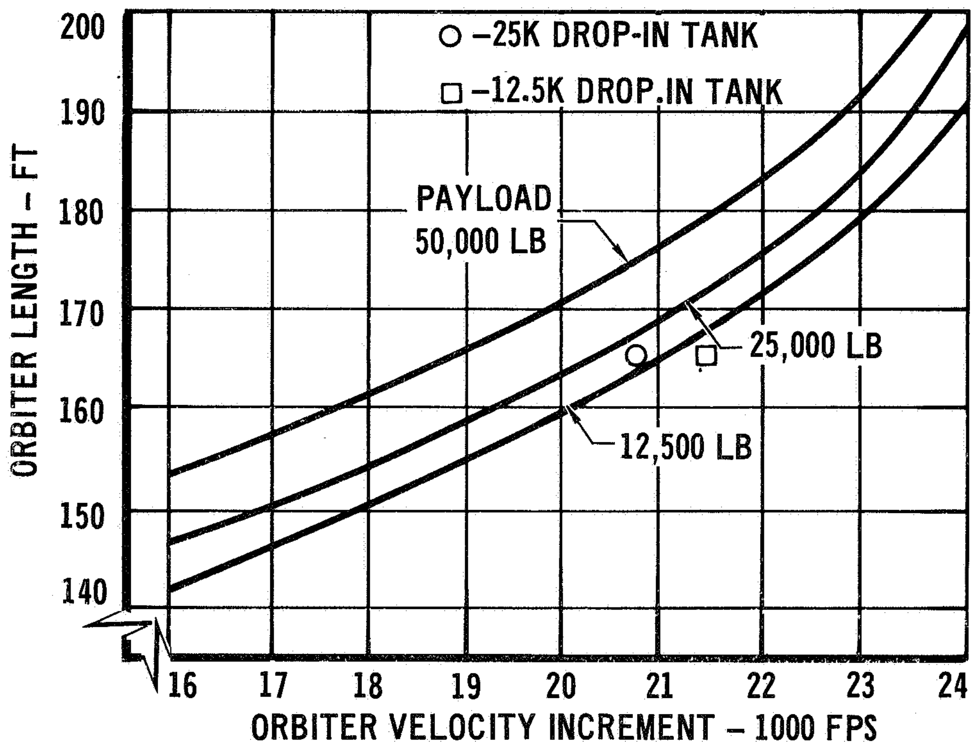


FIGURE 3-32

ORBITER MASS FRACTION VARIATION

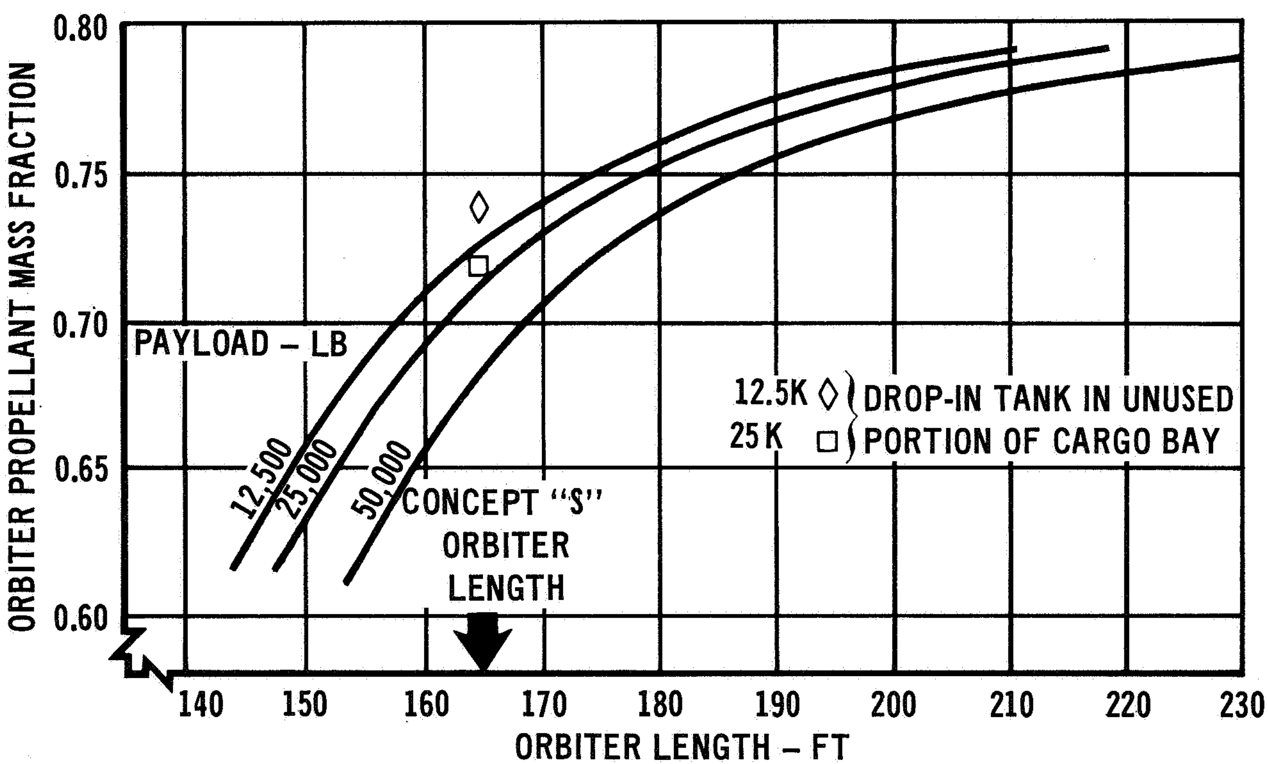
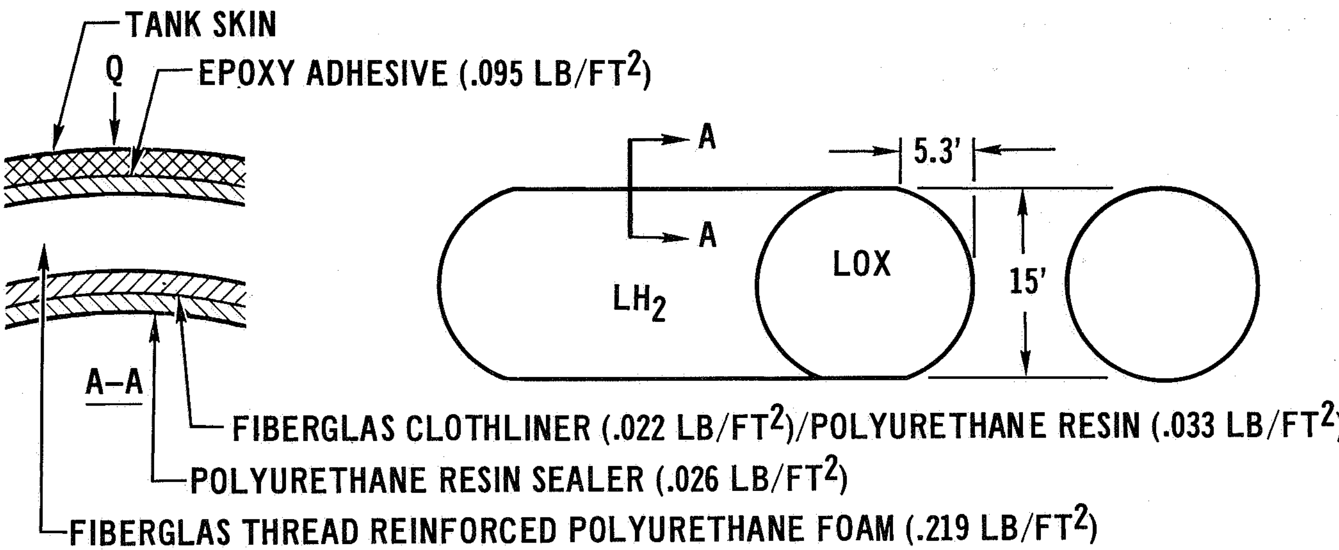


FIGURE 3-33

DROP-IN TANK SIZING



	WEIGHT – LB			
	60 FT	45 FT	30 FT	15 FT
SIDEWALL	1470	1020	580	130
BULKHEADS	460	460	460	310
INSULATION	860	660	450	310
LINES, VALVES, FITTINGS	600	540	380	190
TOTAL TANK WEIGHT	3390	2680	1870	940
PROPELLANT – MR = 6:1				
USABLE	210,180	154,720	98,380	42,780
RESIDUAL	2,120	1,560	990	430

FIGURE 3-34

from 15 to 60 ft. The tanks are a common bulkhead design with the bulkhead height equal to .707 times the tank diameter. An allowance was made for lines, valves and fittings required to pump the fuel from these tanks into the tank located back of the aft payload bay bulkhead. The usable propellant capacity is shown along with the tank weights. A one percent propellant residual was allowed. Parallel burn of core stage engines at lift-off was a NASA imposed study constraint. Figure 3-35 defines the weight added for a propellant transfer system. The propellant is transferred by pumping from tank to tank across the core stage interface.

This level of detail provided all the data required to size the core stages pending selection of a baseline configuration. Selection of the baseline, however, requires an evaluation of the effect of sizing options on the total vehicle. Before this could be accomplished, an equivalent definition of zero stage sizing data was required.

Zero Stage Evaluation - The basic data for evaluation of the zero stages was supplied by the NASA and included definition of expendable earth storable liquid and segmented solid stages with appropriate burn-out weight and adjustment for reusability.

The segmented solid data was supplied in the form of specified design points for three and four segment 156 inch diameter motors and a seven segment 120 inch diameter motor. The 156 inch data was extrapolated to define one to five segment motors. This was accomplished by extracting segment and closure sizes from the reference data and recombining them in the desired combinations. Figure 3-36 describes the solid motor specific impulse as well as the segment and closure data inferred from the 156 inch motor design points. A similar approach for a 120 inch motor size was not possible. In addition, early results indicated that the 120 inch diameter motors were too small to be generally applicable to the siamese concept. Therefore, only the 156 inch diameter motor data was used throughout the study.

The results of the solid motor extrapolation are shown in terms of weight and length in Figure 3-37. This figure gives an indication of the physical size of these large motors. The loaded motor weight and length in the region of interest are in the same range as the core vehicles. The weight increment between expendable and reusable motors reflect the addition of 10% of the burn-out

PROPELLANT TRANSFER WEIGHT PENALTY

	BOOSTER		ORBITER	
ITEM	LO_2	LH_2	LO_2	LH_2
• PUMP	850	870	–	–
• SHUTOFF VALVE	80	80	80	80
• BELLOWS/DISCONNECT	360	360	180	180
• LINES/FITTINGS	380	740	240	290
• TOTAL/STAGE	3720		1050	
• TOTAL	4770			

FIGURE 3-35

NASA SUPPLIED SOLID ZERO STAGE DATA

156" SOLID MOTOR DATA	
SEGMENT WEIGHT – LB	303,020
SEGMENT PROPELLANT – LB	270,000
SEGMENT LENGTH – IN.	250
FWD/AFT CLOSURE WT – LB	390,370
CLOSURE PROPELLANT – LB	302,000
CLOSURE LENGTH – IN.	900
SEA LEVEL I_{SP} – SEC	237.0
VACUUM I_{SP} – SEC	263.5

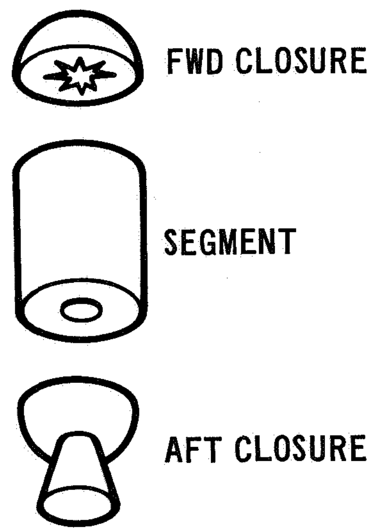


FIGURE 3-36

ZERO STAGE SOLID MOTORS

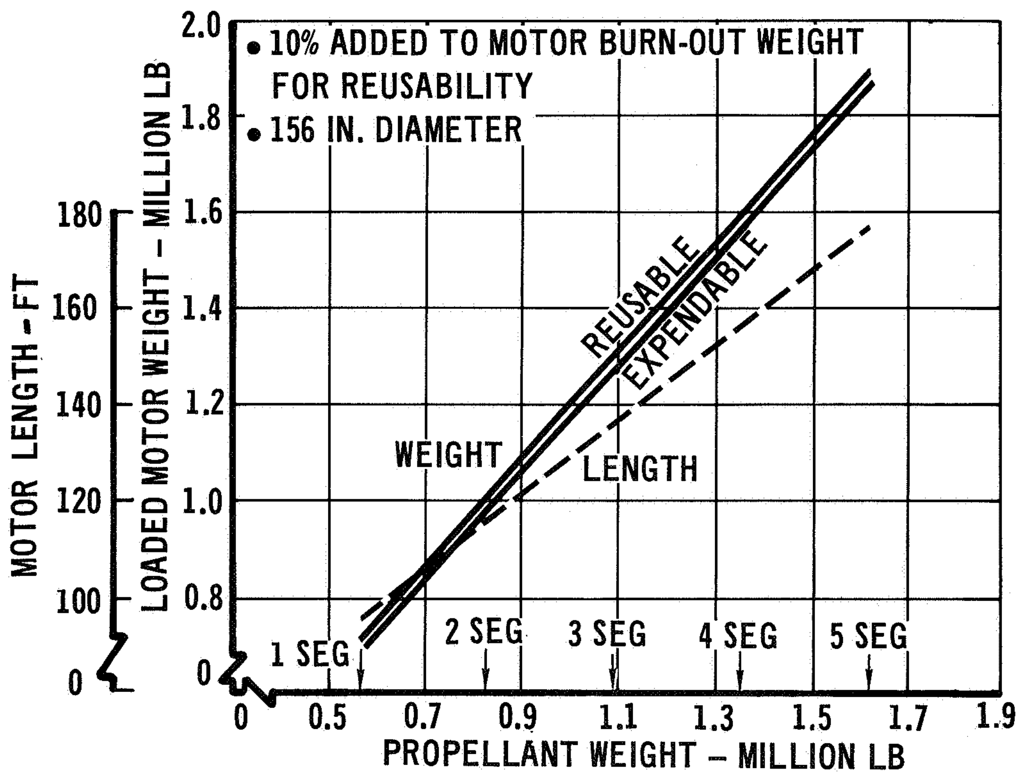


FIGURE 3-37

weight for reusability. This effect is more readily apparent through examination of the motor mass fraction as shown by Figure 3-38. A decided advantage is found for this stage over the mass fractions calculated for the core stages. The improvement is approximately ten percent for corresponding stage weights.

The NASA supplied an equation for earth storable bipropellant zero stages relating the mass ratio to launch weight and engine sea level thrust. A reduced form of the equation is shown in Figure 3-39 with definition of the appropriate inputs as well as stage specific impulse. A ten percent increase in burn-out weight was added as directed by the NASA to provide for mounting pads and associated strap-on structure. Figure 3-40 shows liquid zero stage mass fractions developed from the equation. As previously indicated for the solid stages, a 10 percent burn-out weight increment was added for reusability. Since the equation indicated a thrust dependency, the mass fractions were defined for a range of applicable thrust levels. As shown thrust has a very little effect on the mass fraction values. The liquid stage mass fractions are virtually identical to the solid stage mass fractions at equal stage weights.

The liquid stage weight equation requires two data inputs, namely engine and valves weight and stage nose cone weight. Figure 3-41 is included to show the contribution of the engine and valve weight expression. Existing engines weights are plotted on the figure to show how the relationship approximates the weight of current designs. The nose cone weight shown in Figure 3-42 was developed by McDonnell·Douglas during the study. The weights shown were derived to be consistent with current launch vehicle nose cone angles of 34^{o}. Using this data, the nose cone weights are defined by the base diameter.

Completion of the zero stage sizing analysis supplied the relations required to define the composite vehicles. Therefore the second phase of the study was initiated to define the effects of the various stage sizing options and select a baseline design concept.

B. Sizing Options Analysis - The intent of the sizing analysis was parametric in nature rather than optimization of the concept. The size of a vehicle designed to perform a given mission is influenced by many factors. The prime factors affecting vehicle size are as follows:

SOLID MOTOR MASS FRACTIONS

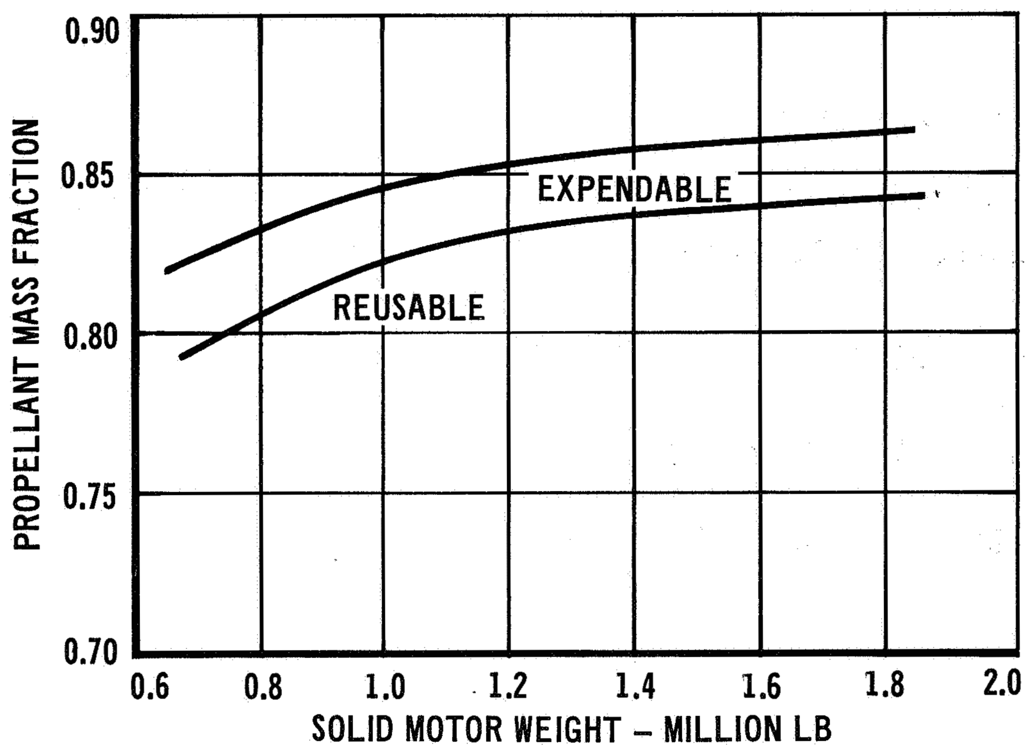


FIGURE 3-38

NASA SUPPLIED LIQUID ZERO STAGE DATA

- LIQUID STAGE EQUATION

$$W_{BURN\text{-}OUT} = 0.111\, W_{LAUNCH} + 1.11\, [W_{ENG\,+\,PROP\ VALVE} + {}^{*}W_{NOSE\ CONE}]$$

(*INCLUDES 10% BURN-OUT WEIGHT CONTINGENCY)

$$^{*}W_{ENG\,+\,PROP\ VALVE} = \left[\frac{F_{SEA\ LEVEL}}{122.5}\right]\left[\frac{F_{SEA\ LEVEL}}{106}\right]^{0.027}$$

- SEA LEVEL SPECIFIC IMPULSE = 220 SEC
- VACUUM SPECIFIC IMPULSE = 267 SEC

FIGURE 3-39

PROPELLANT MASS FRACTION OF THE LIQUID ZERO STAGES

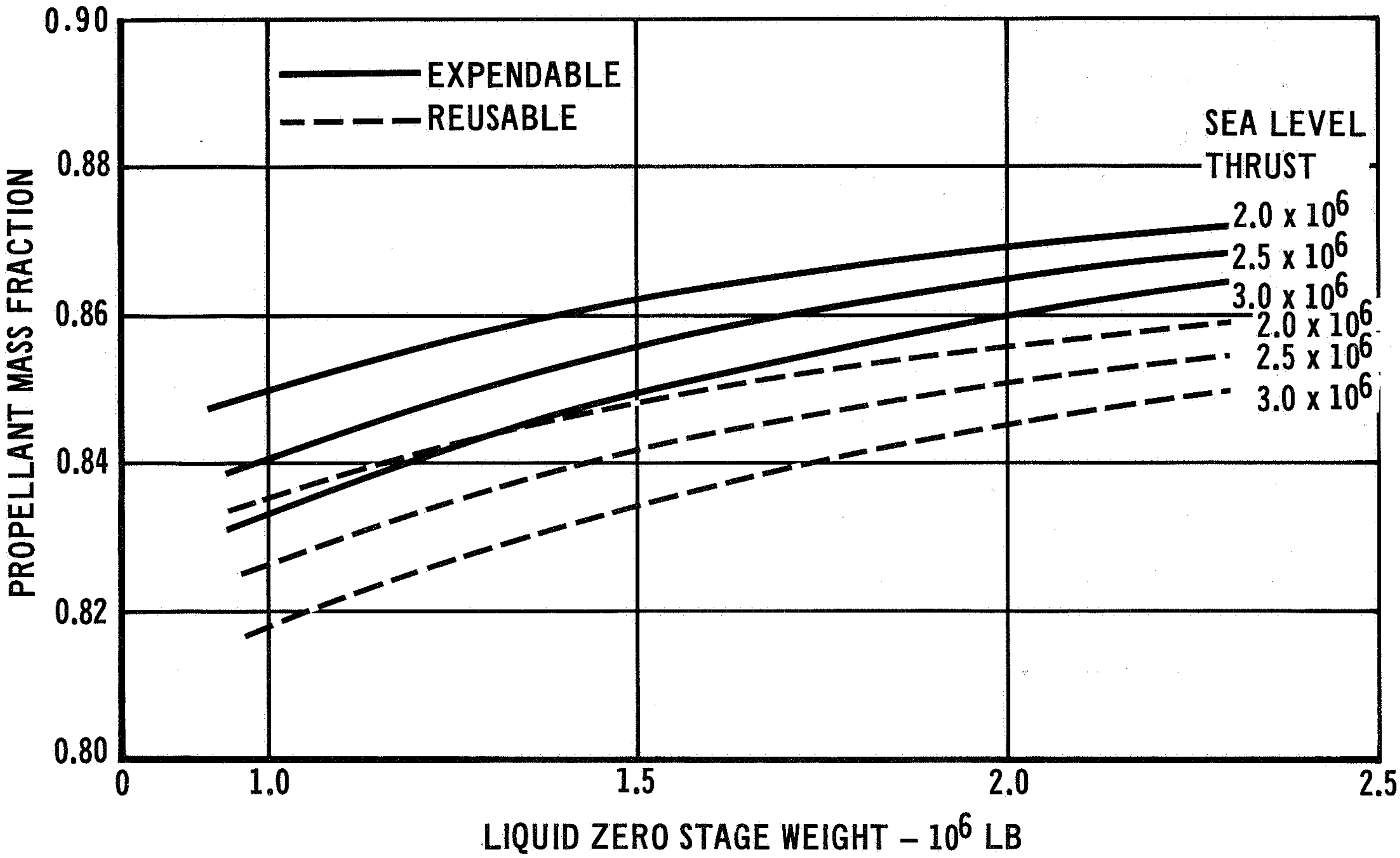


FIGURE 3-40

LIQUID ENGINE AND VALVE WEIGHT

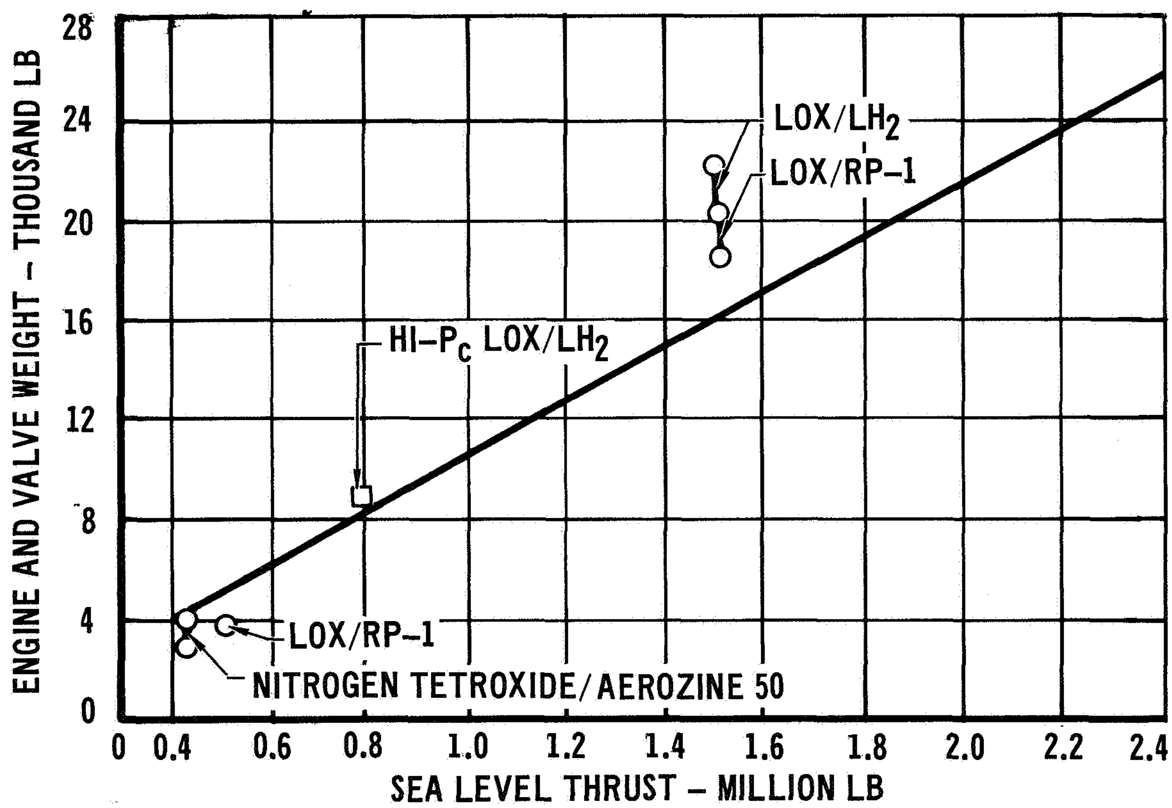


FIGURE 3-41

NOSE CONE WEIGHTS

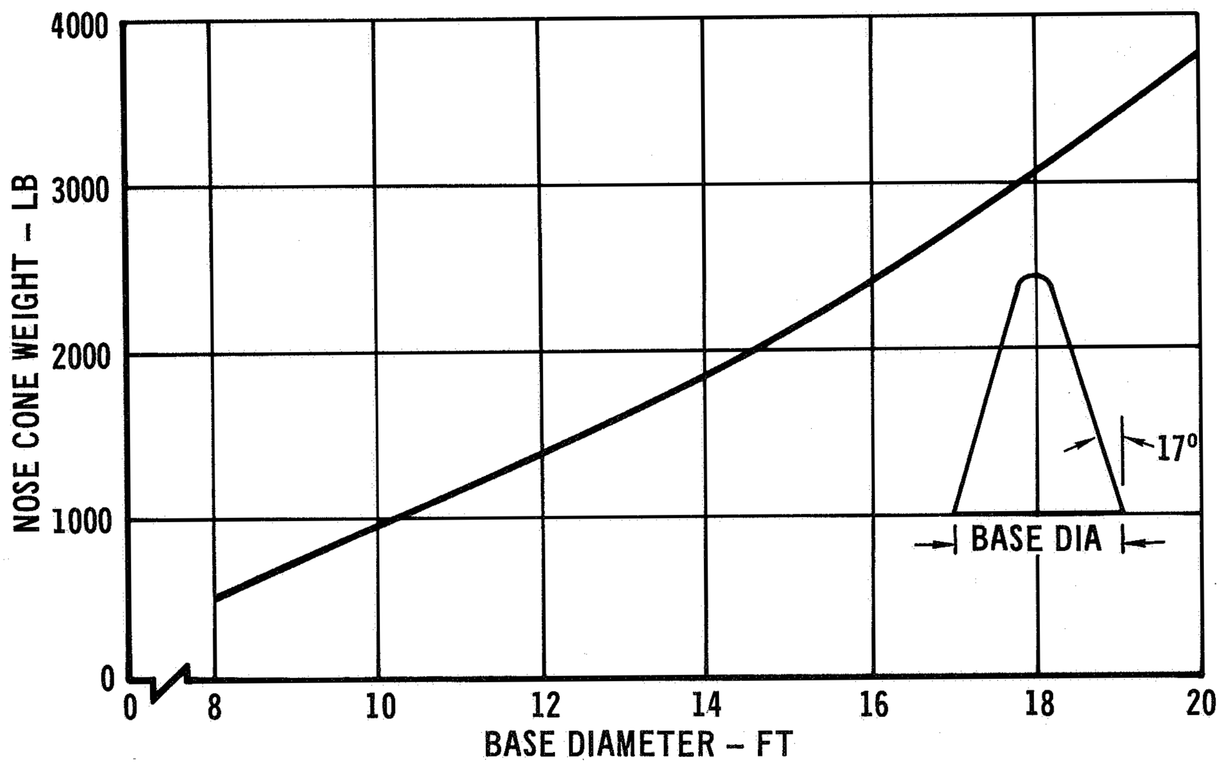


FIGURE 3-42

1) Orbiter Characteristic Velocity - Provides an index of the energy contribution of each state. This velocity parameter is the major contributer to the payload effectiveness of the vehicle (Payload per pound of gross-launch-weight).
2) Use Rate of Zero Stage Propellant - Controlled by zero stage thrust level and is prime influence on limiting velocity losses.
3) Booster Propellant Fraction Used During Zero Stage Burn - Controlled by booster engine thrust setting during zero stage operation. Affects staging efficiency (amount of inert weight carried by each pound of propellant).
4) Rate of Booster Propellant Use During Zero Stage Burn - Controlled by boost engine thrust profile during zero stage burn. Affects velocity losses.
5) Physical Design Limits - Controls the extent to which the other prime factors can be exercised. Sets limits on initial thrust-to-weight, maximum dynamic pressure, maximum acceleration as a function of structural and thermal constraints. Establishes limits associated with parallel burn and available throttle ratio.

For an in-depth design of the siamese concept the design limits would be selected by exhaustive trade study analysis. That, however, was beyond the scope of the current study. The constraints for this study are outlined in Figure 3-43. The initial thrust-to-weight ratio was taken from the SAMSO STS Study. Parallel burn and differential throttling thrust vector control was directed by the NASA. The throttle ratio selected is consistent with projected hardware developments. Dimensional constraints were established for zero stages to simplify drag estimates.

Sizing Effects Analysis - A computer program was developed to generate vehicle sizing data. Figure 3-44 is a flow chart of the program showing the vehicle size definition analysis. The basic sizing method was to input an ideal mission velocity (including losses) and a given core vehicle. The programs then compute the zero stage sizes within the constraints imposed by the sizing ground rules. The analysis mechanism consists of (1) assuming a zero stage propellant weight in order to calculate thrust and burn time, (2) define an effective specific impulse value including the core

PROPULSION STUDY CONSTRAINTS

- 1.35 INITIAL SEA LEVEL THRUST-TO-WEIGHT
- PARALLEL BURN AT LIFT-OFF
- 10 TO 1 MAXIMUM VACUUM THROTTLE RATIO
- DIFFERENTIAL THROTTLING THRUST VECTOR CONTROL
- 156 IN. MAXIMUM SOLID MOTOR NOZZLE EXIT DIAMETER
- LIQUID STAGE TANK DIAMETER EQUAL TO NOZZLE EXIT DIAMETER
- POSSIBLE NOZZLE SEPARATION PERFORMANCE EFFECTS IGNORED

FIGURE 3-43

Optimized Cost/Performance Design Methodology

ZERO STAGE
SIZING PROGRAM FLOW CHART

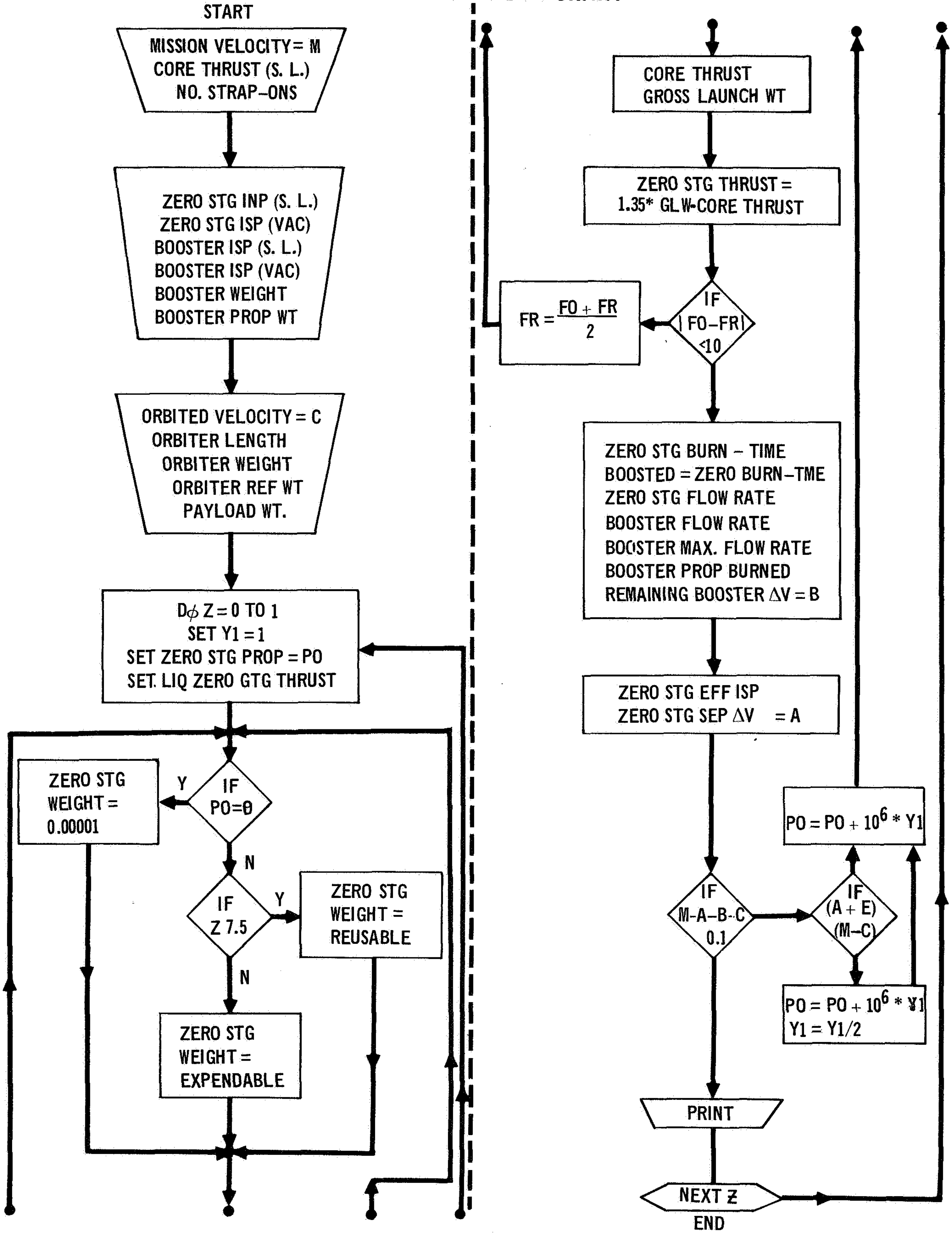


FIGURE 3-44

stage propellant used during the zero stage burn, and (3) compute the total ideal velocity, then compare it to the desired value and iterate until the accuracy is acceptable.

Utilizing the vehicle sizing program, the influence of varying design and performance characteristics is obtained. Figure 3-45 demonstrates the effect of varying the amount of booster propellant used during zero stage operation. Note that 100% usage approximates a two stage vehicle while decreasing the propellant approaches a three stage operation. The percent of booster propellant used is proportional to the average core stage thrust. In order to decrease the propellant used the core stage engines must be throttled down. Maintaining the parallel burn directive and the 10 to 1 throttle ratio ground rule, the propellant percentage could not be reduced below ten. Core stage thrust reduction requires an increase in zero stage thrust to maintain the 1.35 lift-off thrust-to-weight. The resulting thrust-time profile has the net effect of increasing the inertial velocity as a function of altitude causing an increase in maximum dynamic pressure. Therefore, the percent of propellant reduction is established by maximum dynamic pressure. As indicated a dynamic pressure of 900 psf is experienced at 50% level. Further reduction appears impractical, since this pressure level is considered a reasonable upper limit for this concept.

Additional reduction is available by shaping the thrust profile of the core stage engines. In this manner it is possible to achieve the same or smaller integrated pressure effect while consuming less boost stage propellant. A simple linear core stage thrust profile was assumed which would reduce the zero stage thrust and increase the burn time resulting in lower velocity at the maximum dynamic pressure condition. The core stage thrust at lift-off was set at a percentage of full thrust and linearly throttled to 10% over the burn time of the zero stage. Figure 3-46 illustrates the effect of this method of shaping the use rate of booster propellant expended during the zero stage operation. As shown in a continual weight reduction results from reducing the core stage thrust level at lift-off. Note that with this thrust profile the 100 percent lift-off thrust corresponds to an average of 55 percent. This level roughly corresponds to the previous level where further reduction was limited. Continual reduction is available with this thrust profile down to a 30 percent core stage

EFFECT OF USING BOOSTER PROPELLANT DURING ZERO STAGE BURN

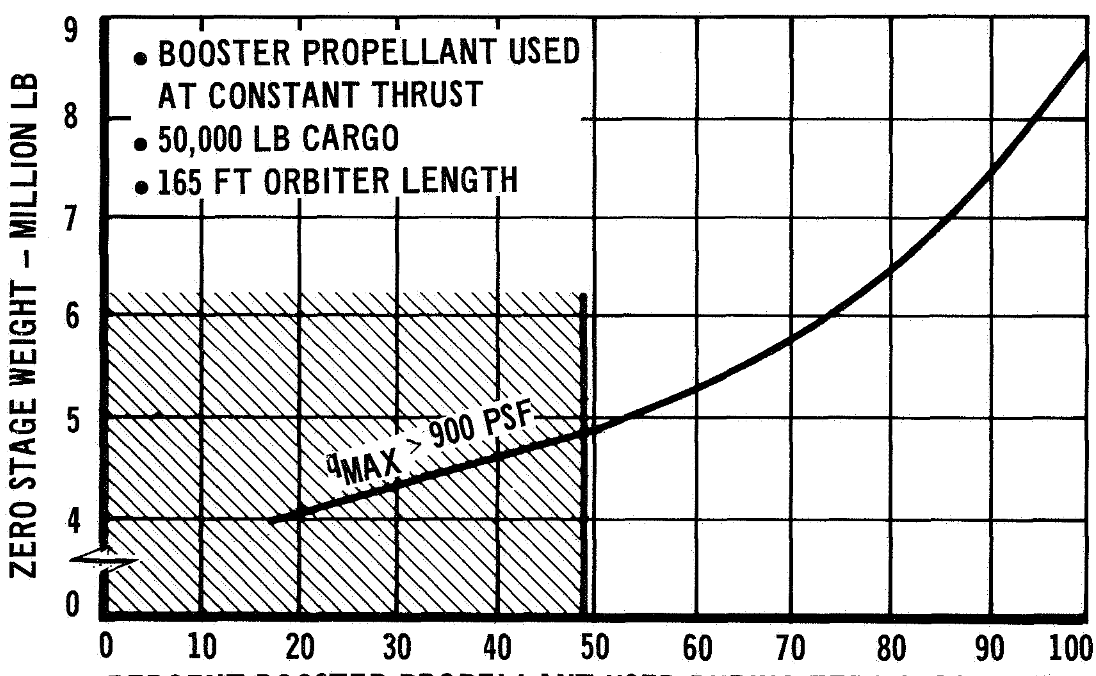


FIGURE 3-45

EFFECT OF BOOSTER PROPELLANT USE RATE

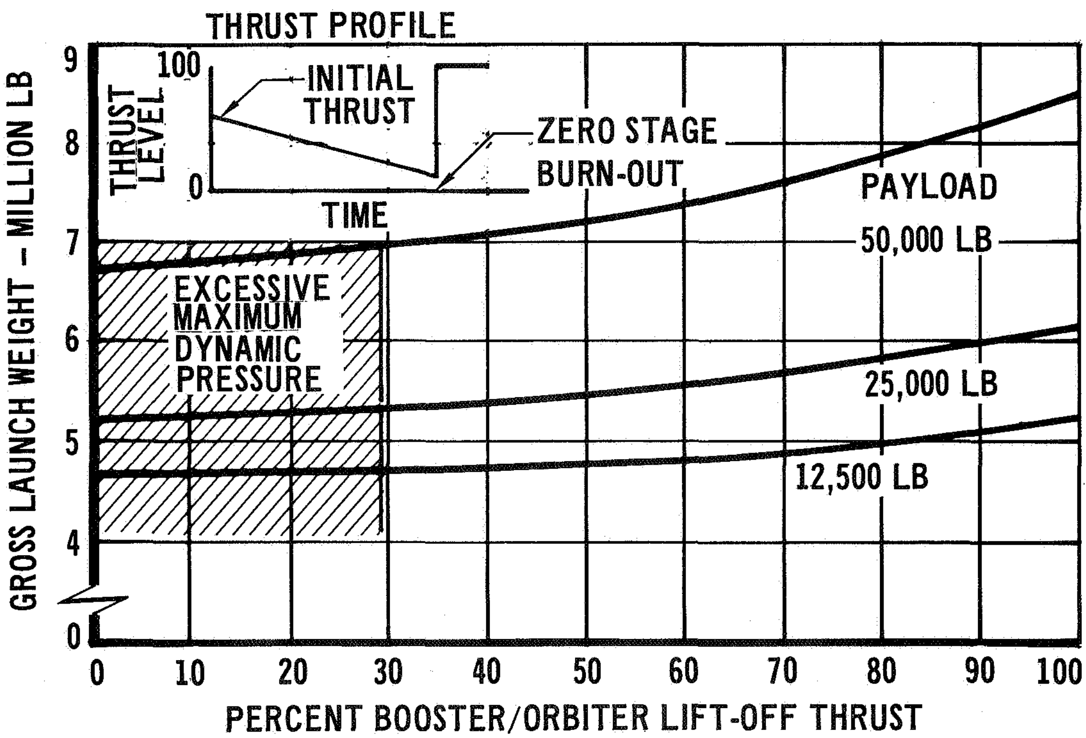


FIGURE 3-46

lift-off thrust level. This roughly corresponds to a booster propellant expenditure of 18 percent during the zero stage operation. Since very little is to be gained by going lower this thrust profile was selected without further shaping.

The remaining effect requiring demonstration is the orbiter characteristic velocity. This parameter has the greatest overall effect on vehicle size. This is demonstrated in Figure 3-47 for solid propellant zero stages. The characteristic velocity plotted includes a 2,000 fps on-orbit maneuvering budget. As shown, the gross launch-weight for a given payload varies very rapidly with the orbiter velocity increment. The minimum gross-launch-weight for all three payloads occurs in a very narrow velocity band: 22,250 fps to 22,500 fps. The corresponding core stage lengths vary between 168 and 177 ft. The variation of gross-launch-weight with payload is surprisingly small. This indicates that the payload efficiency (gross-launch-weight/payload) increases very rapidly in the region shown. The numerical values are 125 pounds, 220 pounds and 411 pounds of lift-off weight per pound of payload for 50,000, 25,000 and 12,500 lb. payloads respectively. Therefore, there is a major advantage to selecting a large payload on a pounds for pound basis. Figure 3-48 shows the same orbiter characteristic effects using liquid zero stages. This velocity also includes the 2000 fps on-orbit budget. The minimum gross-launch-weight for liquid zero stages occurs at a slightly lower level than the solid: 20,900 to 21,200 fps. The corresponding stage lengths are also slightly different: 167 to 176 ft. Otherwise the results of Figures 3-47 and 3-48 are virtually identical.

Baseline Concept Selection - Consideration of the sizing effects analysis reveals that a realistic region of sizing options exists. Figure 3-49 defines the region which is bounded by the high and low payloads, minimum gross-launch-weight and the model orbiter characteristic velocity. Within this region three logical baseline core stage sizing options exist. They include the following:

1) Minimum Gross-Launch-Weight - This line represents the highest performance of a two and one-half stage vehicle design across the payload range.
2) Constant Orbiter Characteristic Velocity - The characteristic velocity of the model orbiter is representative of the highest performance of a two stage vehicle design.
3) Constant Core Vehicle Length - The model orbiter with drop-in tanks

ORBITER CHARACTERISTIC VELOCITY EFFECT ON GROSS LAUNCH WEIGHT SOLID ZERO STAGE

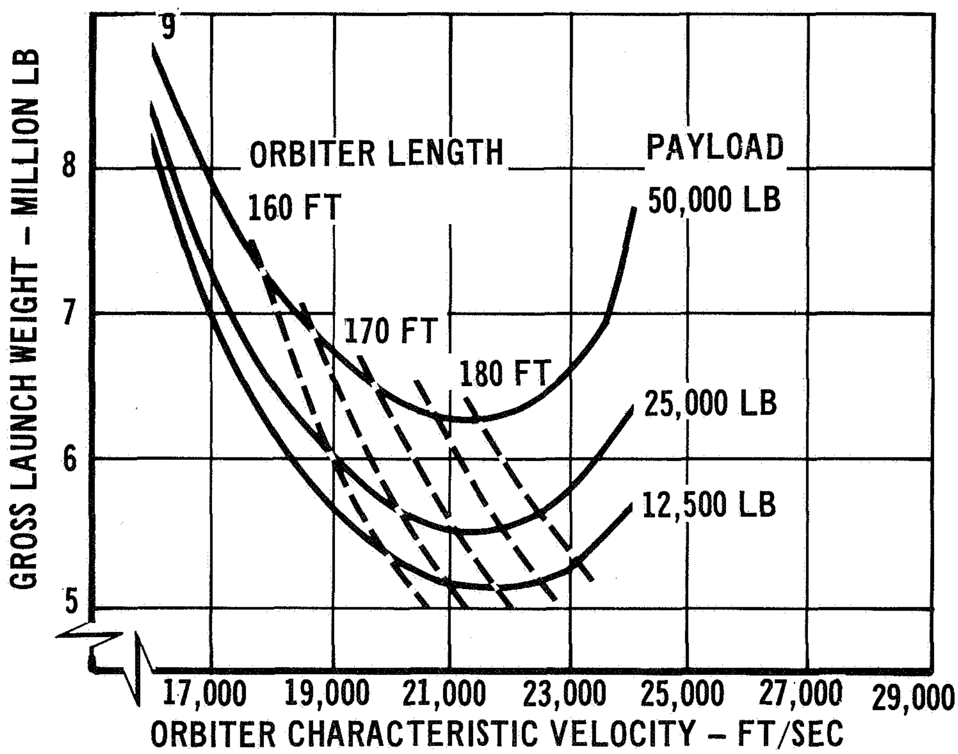


FIGURE 3-47

ORBITER CHARACTERISTIC VELOCITY EFFECT ON GROSS LAUNCH WEIGHT
Liquid Zero Stage

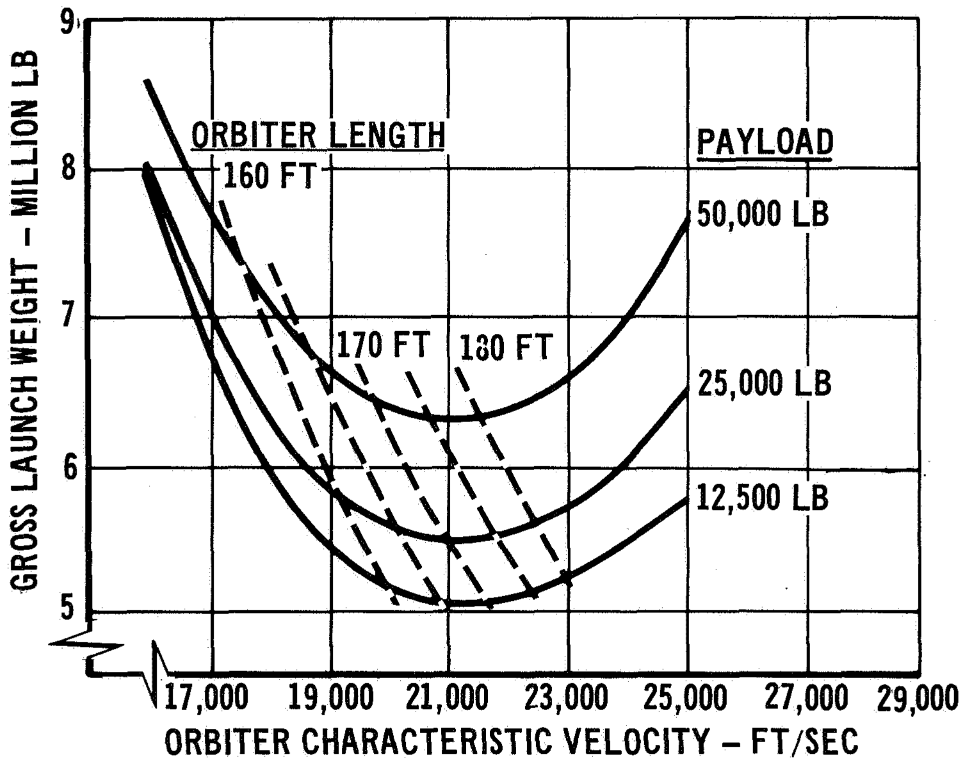


FIGURE 3-48

REGION OF SIZING OPTIONS

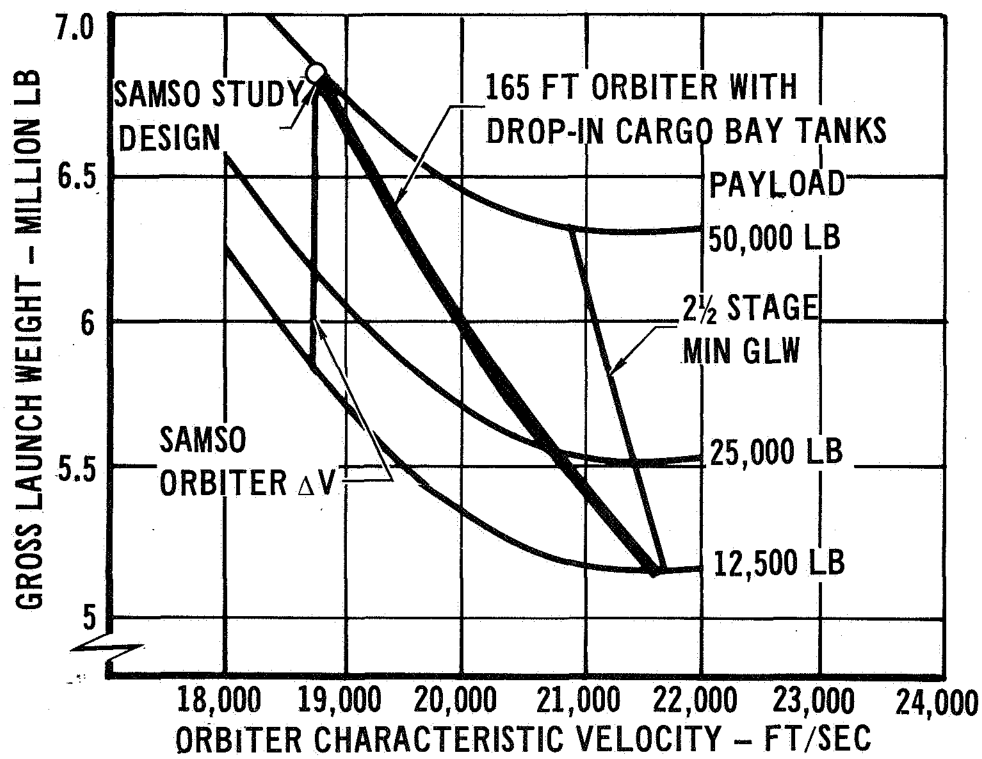


FIGURE 3-49

spans the entire sizing region. It is bounded by the constant orbiter characteristic velocity at the 50,000 lb payload and the minimum gross-launch-weight at the 12,500 lb payload level.

The influence of payload sizes on the core stage sizing, is defined in Figure 3-50. Core stage length and zero stage weight are shown as a function of payload. The figure shows that (1) minimum gross launch weight is achieved with the largest core vehicles and smallest zero stages, (2) the constant ΔV case is characterized by the smallest orbiters and largest zero stages,, and (3) the fixed length core vehicle demonstrates the greatest variation of zero stage sizes.

The core vehicles have been well defined by the SAMSO STS study. The unique feature of the siamese concept is the zero stage strap-ons. Therefore, the most complete definition of the concept hinges on the emphasis placed on the zero stage designs. It would seem then that core vehicle variation would serve less purpose than zero stage variation. Selection of a fixed core vehicle would allow maximum utilization of the depth of definition of the two stage vehicles while providing for maximum zero stage design data variations. As a results, the confidence level in the accuracy of the core stage data and the versatility of the zero stage sizing data are maximized. Consequently the fixed length core vehicle was selected as the baseline concept whose basic characteristics are as follows:

(1) Booster/Orbiter Length - 165 ft

(2) Orbiter Characteristic Velocity

 50,000 lb Payload - 18,790 fps

 25,000 lb Payload - 20,675 fps

 12,500 lb Payload - 21,675 fps

(3) Payload Density - 4.72 lb/ft^3

(4) Payload Diameter - 15 ft

(5) Payload Length

 50,000 lb Payload - 60 ft

 25,000 lb Payload - 30 ft

 12,500 lb Payload - 15 ft

C. Zero Stage Sizing - The resolution of a baseline concept completed the second phase of the siamese vehicle sizing evaluation. The concluding

SIZING OPTIONS EFFECT ON STAGE SIZE

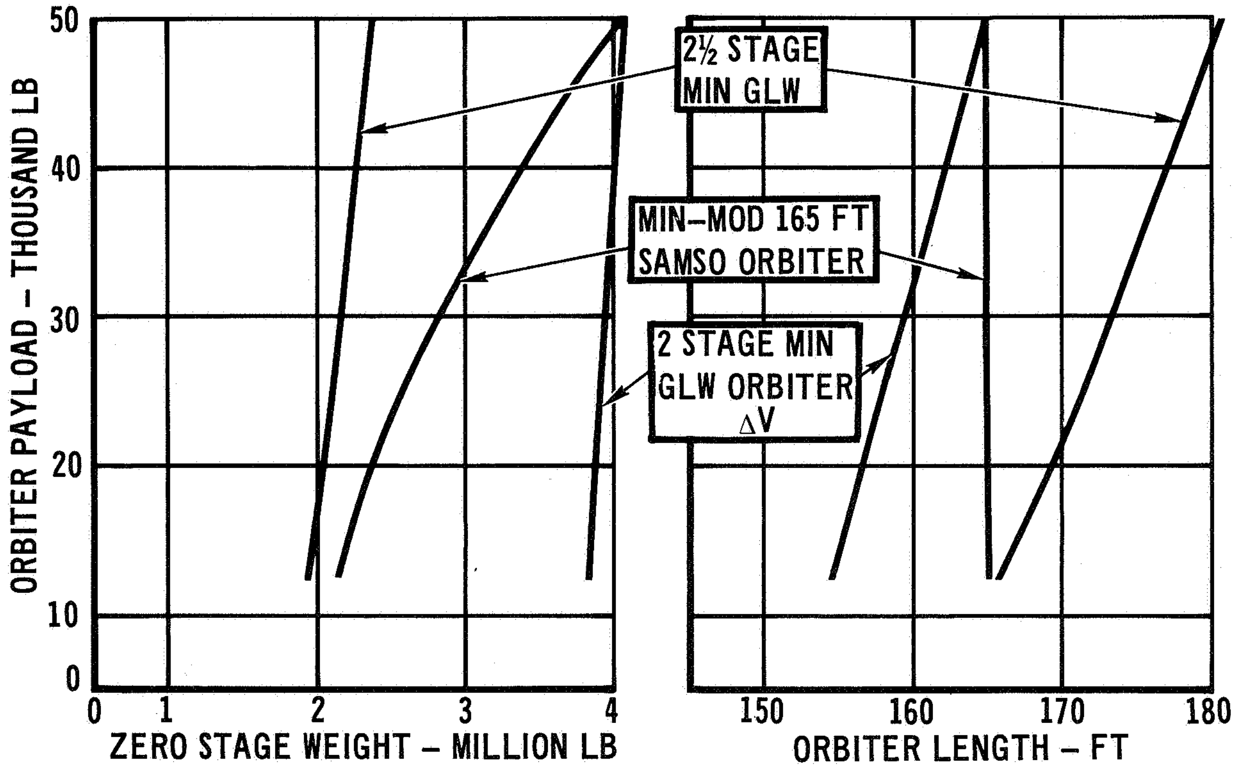


FIGURE 3-50

task was to improve the design definition accuracy of the baseline points. The computer program used for the sizing effects analysis was utilized to make successive iterations of zero stage designs. A data point was run on a trajectory program, velocity losses defined and a value for ideal characteristic velocity generated. This velocity was then input into the sizing program to refine the previous stage size. Results were then compared and iterated for both zero stage and ideal velocity until the ΔV variation was less than 50 fps. In addition, stage data was developed, by extrapolation, for two characteristic velocities representing the other core stage sizing options. The results are approximate, but serve to more clearly illustrate siamese vehicle zero stage design characteristics.

<u>Baseline Zero Stage Definition</u> - The segmented solid zero stages are all based on the 156 inch motor data. The solid motor propellant was determined by the weights and staging velocities of the core vehicles. The thrust level was established by successive iterations of the 1.35 thrust-to-weight ratio and the core stage thrust at lift-off. The physical magnitude of zero stage thrust levels presented a problem in stages of this size.

Figure 3-51 demonstrates the situation. Using two motors the nozzle exit diameter approximates or exceeds the motor case diameter at the thrust levels of interest. This complicates the aerodynamic drag considerations for adding a conical aft stage and increases the cross sectional area. More important, there are considerations for feasible grain design which must be included. Although it is a complex phenomena and difficult to analyze, there are physical limitations to propellant mass fraction established by unstable erosive burning. Control over uneven burning is established by control of combustion product velocity in the grain port. This is achieved by limiting the throat to port area ratio. For a given burn time and thrust level, this limits the motor case volumetric efficiency. It therefore establishes a limit on mass fraction.

Figure 3-52 illustrates an approximation of the stability limits of a 156 inch motor as a function of thrust. As indicated thrust levels above 3 million pounds have erosive burning problems with a high mass fraction design. Considering both the drag and the grain problems, it was determined that four individual motors were required for each solid zero stage concept. Extending this evaluation it was determined that 120 inch motor diameters are too small for the required thrust levels.

SOLID MOTOR THRUST EFFECT ON NOZZLE EXIT DIAMETER

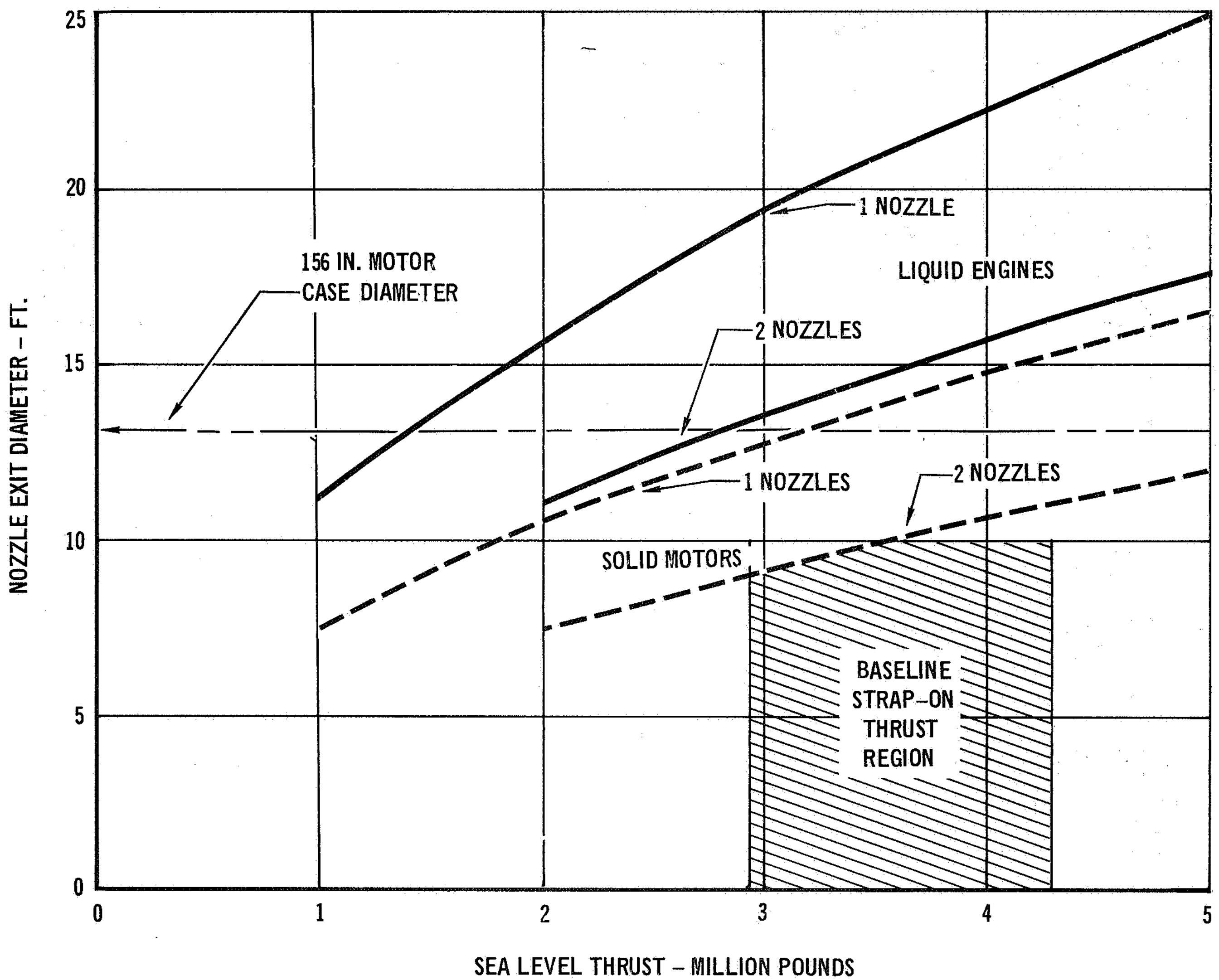


FIGURE 3-51

THRUST LEVEL EFFECTS ON 156" DIA MOTORS

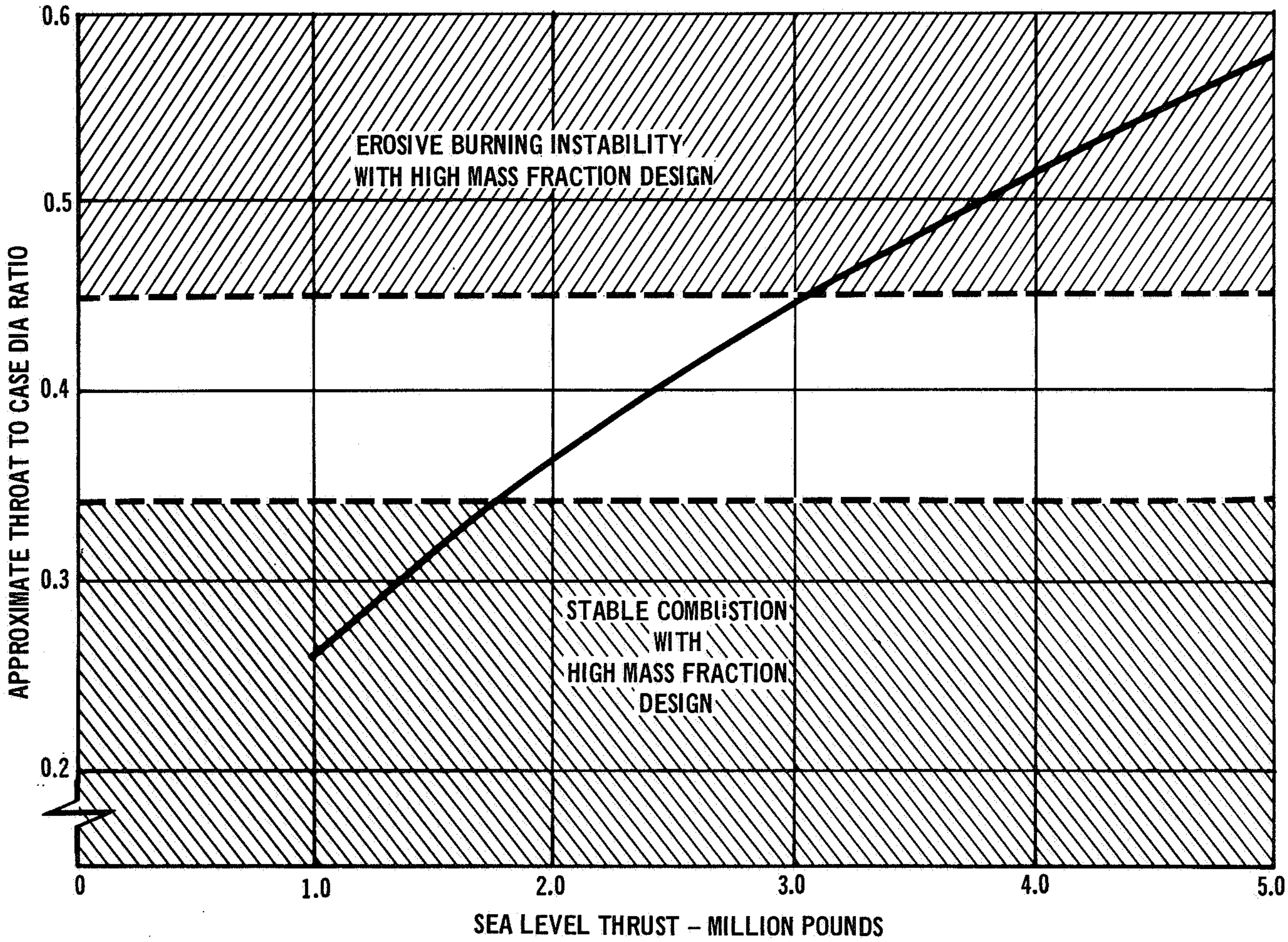


FIGURE 3-52

Applying the four motor design concept to the previously described zero stage sizing the boost trajectory computer programs in successive iterations yielded the baseline data tabulated in Figure 3-53. The characteristics shown on the figure are for individual rocket motors. The weight per motor ranges from 0.6 to 1 million pounds while motor thrust-to-weight ratios vary from 2 to 2.5. Most significant is that the burn times of the motors are quite short for 156 inch type motor with this propellant loading and indicated lengths. The number of segments shown is synthetic, indicating the number defined by the parametric motor data extrapolation. If possible, the existing 156 inch segment motor cases would be loaded to the indicated propellant weight. If that increase (maximum of 8.5 percent) could not be accommodated, the case length could be increased slightly. The zero stage lengths range from 50 to 75 percent of the core vehicle length. Note that the velocity shown is the characteristic velocity at burn-out and includes a booster stage contribution. Combining four of the indicated motors results in total solid zero stage weights of 2.4 to 4 million pounds. Thrust ranging from 6 to 8 million pounds, similar to the Saturn first stage class, are required for the total zero stage.

The earth storable liquid zero stage sizes were derived from the NASA supplied weight equation. In this case it was necessary to specify a configuration in order to complete a set of baseline stage design definitions. Two alternates were considered as practical configuration candidates. The first was a tandem tank, single engine, strap-on. The second is a side-by-side, parallel tank two engine strap-on. The tank diameters were arbitrarily set equal to the exit diameter of the engine in order to simulate a low drag configuration. Since both the tandem and parallel tank concepts have the same drag cross section (engine exit area), other factors were considered in the configuration selection.

The twin engine strap-on configuration is shorter, has less skin friction, and a more compact profile. Although not quantitatively proven, it was estimated that this configuration would have the higher performance characteristics of the two considered. In the case of the tandem tank, single engine, design, the development of three to four million pound thrust low pressure engines seems improbable. As a

SOLID ZERO STAGE DATA
BASELINE CONFIGURATION
(CORE VEHICLE LENGTH-165 FT.)

CHARACTERISTIC VARIABLES PER ROCKET	50K – PAYLOAD		25K – PAYLOAD		12.5K – PAYLOAD	
	EXPENDABLE	REUSABLE	EXPENDABLE	REUSABLE	EXPENDABLE	REUSABLE
LOADED WEIGHT (LB)	1,021,015	1,064,270	722,417	751,008	605,448	629,087
PROPELLANT WEIGHT (LB)	863,892	888,245	598,236	612,000	494,171	504,486
SEA LEVEL THRUST (LB)	2,085,810	2,144,200	1,699,120	1,737,710	1,552,670	1,584,580
BURN TIME (SEC)	98.2	98.2	83.4	83.5	75.4	75.4
NOZZLE EXIT DIA (FT)	11.8	12.0	10.7	10.8	10.2	10.3
NUMBER OF ROCKETS	4	4	4	4	4	4
EXIT AREA (FT^2)	110.2	113.3	89.8	91.8	82.0	83.7
NUMBER OF SEGMENTS	2.08	2.17	1.10	1.15	0.71	0.75
STAGE LENGTH (FT)	118.4	120.2	97.8	98.9	89.8	90.6
STAGING VELOCITY* (FPS)	7,021	7,022	5,567	5,567	4,864	4,865

*INCLUDES BOOSTER STAGE OPERATION

FIGURE 3-53

result, the parallel tank twin engine zero stage strap-on was selected as the most likely candidate.

The baseline design consists of two strap-ons, each composed on one fuel tank and one oxidizer tank, mounted side-by-side, with two engines. As shown in Figure 3-54 the stage parameters are very similar to the solid zero stages for corresponding cases. The liquid stages are slightly smaller in overall size. As a result, the burn times are also slightly lower. The stage lengths indicated do not include an engine section but are significantly shorter than the solids because the tank diameters are greater than 13 ft (156 inches). The difference is less pronounced as payload and tank diameter correspondingly decreases.

LIQUID ZERO STAGE DATA
BASELINE CONFIGURATION
CORE VEHICLE LENGTH-165 FT.)

CHARACTERISTIC VARIABLES PER SET***	50K – PAYLOAD		25K – PAYLOAD		12.5K – PAYLOAD	
	EXPENDABLE	REUSABLE	EXPENDABLE	REUSABLE	EXPENDABLE	REUSABLE
LOADED WEIGHT (LB)	1,965,539	2,056,034	1,343,146	1,393,059	1,098,367	1,135,673
PROPELLANT WEIGHT (LB)	1,695,430	1,746,220	1,151,980	1,175,780	938,110	954,163
SEA LEVEL THRUST (LB)	4,068,370	4,190,520	3,260,950	3,328,340	2,953,430	3,003,790
BURN TIME (SEC)	91.7	91.7	77.7	77.7	69.9	69.9
NOZZLE EXIT DIA (FT)	16.2	16.4	14.5	14.6	13.8	13.8
NUMBER OF SETS	2	2	2	2	2	2
EXIT AREA/MOTOR (FT^2)	410.6	422.9	329.1	335.9	298.1	303.2
NUMBER OF NOZZLES	4	4	4	4	4	4
STAGE LENGTH* (FT)	86.8	87.2	74.9	75.1	68.6	68.8
STAGING VELOCITY** (FPS)	7,085	7,085	5,582	5,581	4,839	4,839

*DOES NOT INCLUDE ENGINE SECTION LENGTH
**INCLUDES BOOSTER STAGE OPERATION
***A SET DEFINED TO CONSIST OF A FUEL TANK, AN OXIDIZER TANK AND AN ENGINE ON EACH.

FIGURE 3-54

3.1.3 Structural Design - This section of the report describes the primary and secondary structure of the basic core vehicles. The body structure consists of cylindrical load carrying integral propellant tanks, frames external to the propellant tanks, the cabin compartment structure and all secondary structure such as hatches, windows and bulkheads. Additional major structural items, such as propulsion thrust structure and wing carry-through structure are also discussed. Weight optimization was primary in design conception and choice of materials.

3.1.3.1 Orbiter/Booster Structure - The primary structural members of the core vehicle's are the load bearing propellant tanks, as shown in Figure 3-55. The two main propellant tanks have circular cross sections with conical lengths joined together as required to follow the body moldline shape thus providing good volumetric efficiency. Tank end domes are .707 ellispe pressure bulkheads. Tank structures are designed locally to carry concentrated loads from the wing carry-through, landing gear, vehicle to vehicle attach points, ground handling attach points, launch thrust loads, and aero control surfaces. The individual tanks are structurally joined to provide a unitized structure. The tank construction basically utilizes boron-aluminum matrix laminates with sufficient plys in the hoop and longitudinal direction to meet strength requirements at various body stations. External rings and stiffeners provide shell stability and serve as load attach points for the truss structure supporting the Thermal Protection System panels, as shown in Figure 3-56. This construction is typical of the entire vehicle except the forward body.

The vehicle forward body is supported by a gradual transition of the circular tank walls to nearly square sections at the forward bulkhead. The forward body structure basically is semi-monocoque construction, with truss supports as required. Local supports carry the three landing engines. The large doors which expose the engines for deployment also permit flow of cooling air into the vehicles between the integral tank structure and the TPS. This cooling provision materially reduces the volume and weight of insulation material required in the vehicles.

The vehicle utilizes a conical thrust shell structure for each of its two boost engines. Propellant lines are arranged to feed each engine independent of the others. The vehicle has a main center landing gear, nose gear and a single outrigger gear on each side. The doors and gear extend conventionally.

CONCEPT "S"
PRIMARY STRUCTURAL CONCEPT

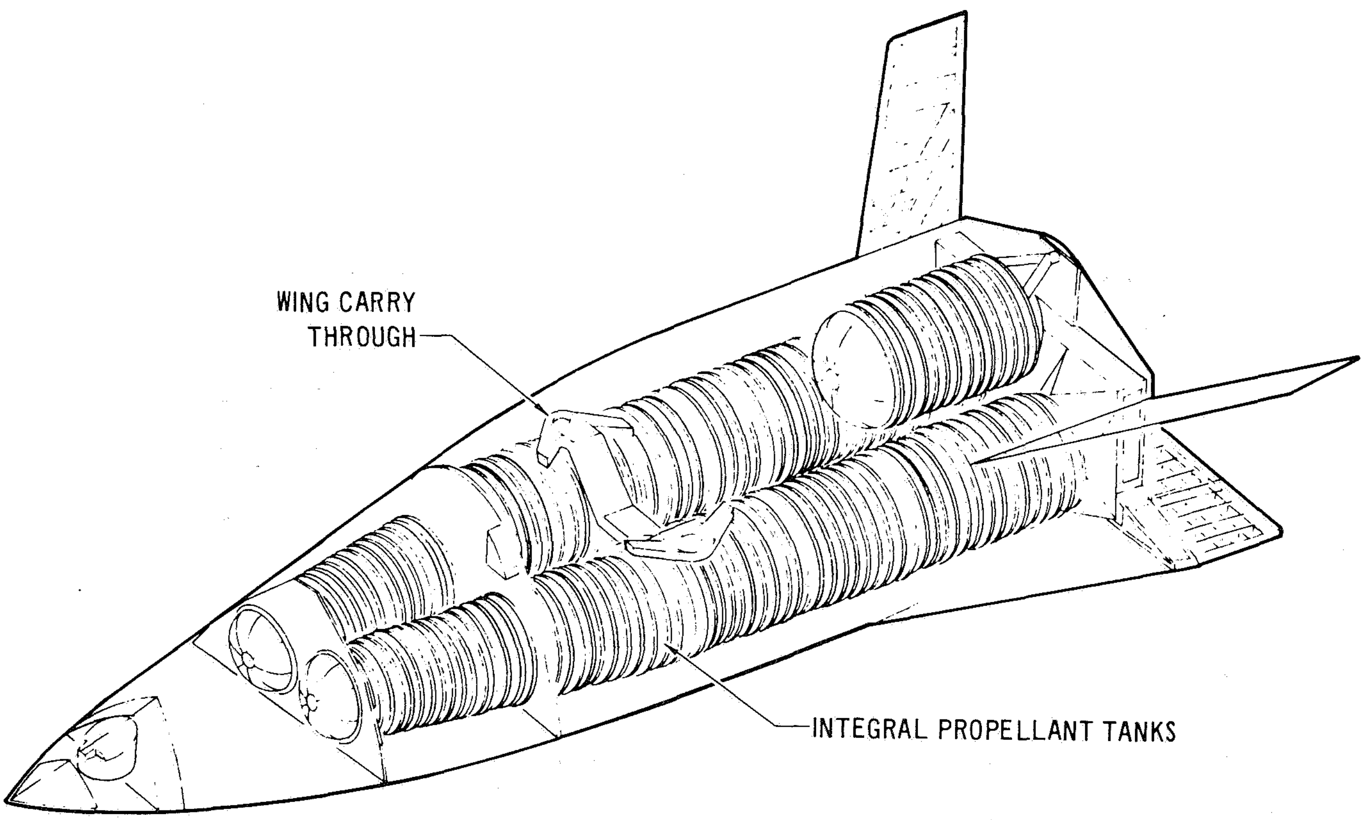


FIGURE 3-55

CONCEPT "S"
SECONDARY STRUCTURE

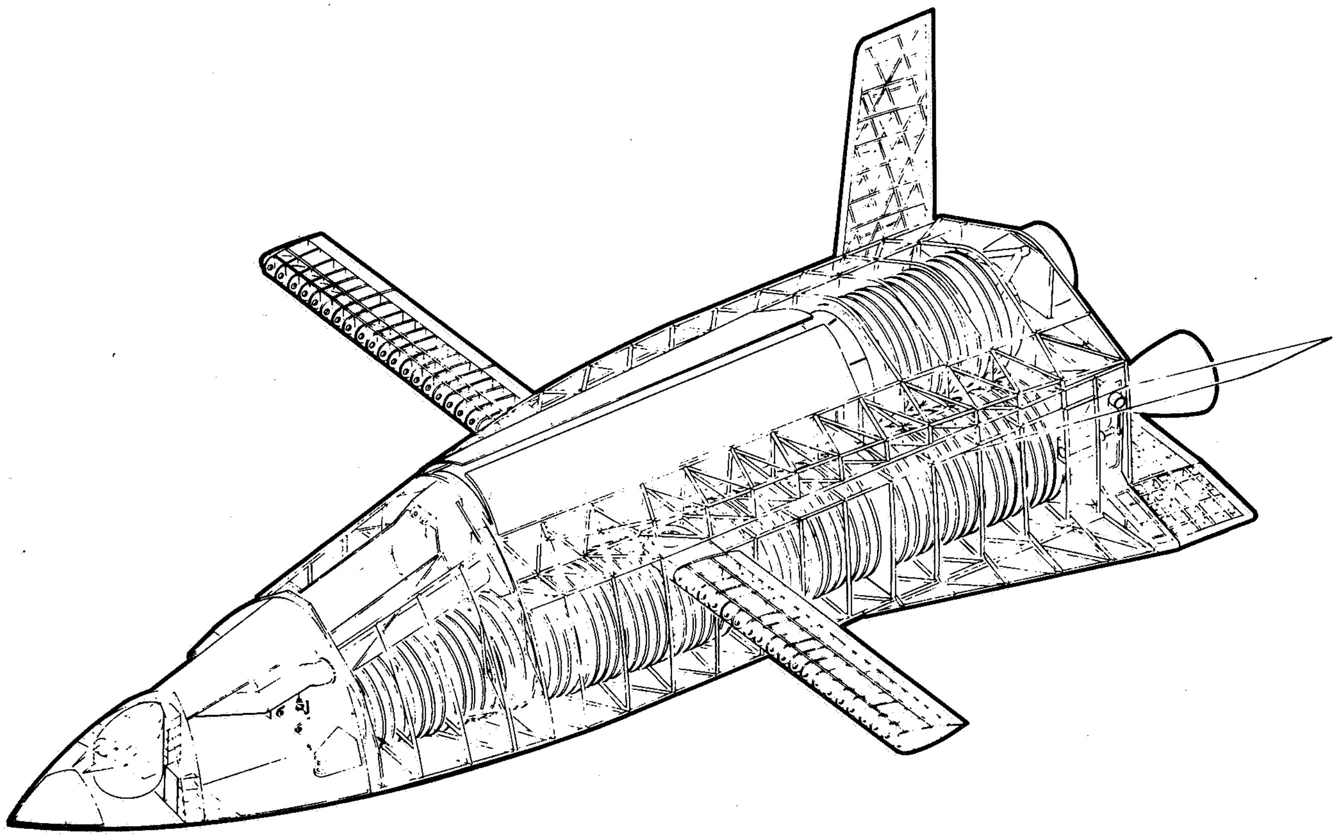


FIGURE 3-56

The vehicle carries the payload in the case of the orbiter, or drop in propellant tank, in the case of the booster, immediately above the main propellant tanks. A pair of doors open the full length of the cargo bay to permit loading and unloading both in orbit and on the ground. The inner panels of these doors serve as space radiators when the doors are swung open. The semi-monocoque doors carry integral structural radiators and are designed with thermal growth allowances compatible with door operation and sealing geometry. The variable geometry wings are stowed just above the propellant tanks and deploy through doors which are segmented and sequenced to open and close with wings in or out. Door segments are required because of the body moldline curvature.

3.1.3.2 Integral Tank Design - The integral tank design concept was chosen as a means of utilizing the large propellant tank structures to serve a dual purpose in carrying primary structural loads while containing boost propellant. Boron-aluminum composite materials were selected for the tanks because of the significant weight saving it affords.

The boron-aluminum composite tank shells are comprised of skins with continuous integral longitudinal stiffeners and separated mechanically attached circumferential rings. Both longitudinal stiffeners and rings are located on the outer surfacr of the tanks primarily to present a smooth inner tank surface for insulation. Although this complicates detail shell design, since the ring flanges must cross the longitudinal stiffeners, the continuous longitudinal stiffeners provide the best structural efficiency.

Locating stiffeners and rings on the outer surface of the tanks has a number of secondary functional advantages. One principle function of the tank shell rings is distribution of TPS truss support loads into the primary tank shell. The externally located rings are well situated to pick up these truss loads as well as other local structure which impose loads on the primary shell structure.

The integral tank shell carries a combination of biaxial stresses and shear stresses. Longitudinal stiffeners function to stabilize the skin panels for both compression and shear panel loading. Shell stiffening rings stabilize the shell for overall compression buckling.

A maximum tank section length of approximately 30 ft is required. This tank section is joined to the next tank section which has a different centerline orientation. Structural kick rings are utilized at the tank to tank skin intersection. It is assumed that the width of a single ply matrix .005 inches thick, containing adjacent parallel boron fibers, is approximately 12 ft. These single plys are then formed on a master mold to provide the proper length and contour in the hoop and horizontal direction. Sufficient layers are included in the bonded matrix to develop required strength and stiffness. Prior to eutectic bonding of the laminants in an autoclave under temperatures and pressure, edging strips are placed in all four edges. The edging strips are sandwiched between all layers to provide a metallic frame thus allowing fusion welding to similar frames. In this manner, tank segments and tank sections can be fusion welded together.

The segmented approach has a potential advantage in permitting a complete panel to be removed and replaced thus salvaging a major assembly in the event of damage.

As noted, strength considerations dictate that external stringers remain uninterrupted and the rings are notched around each stringer. Ring attachment clips may be assembled to the tank in the initial autoclave set up, as a second complete set up, or individually by high frequency welding. The most optimum way has not been determined at this time, however, small scale tests show that all these techniques are feasible.

This design requires no thermal isolation between the liquid oxygen and the tank wall. The liquid hydrogen tank is internally lined with cryo foam insulation on both stages. The oxygen tanks require slosh baffles at longitudinal intervals of 20% of the local radius and radial height of 10% of the local radius. These members are assembled to the tank in a fashion similar to the stiffeners described previously.

3.1.3.3 Wing Carry-Through Structure - The combination of integral tank structure and variable geometry wing requirements presents need for a complex wing load carrying structure. The wing carry-through structure design employs a vertical pin pivot concept to transfer wing lug loads, a main beam structure to carry bending loads, and a set of diagonal beams to balance torque loads. Material used in the carry-through is a combination of titanium alloy and boron-aluminum composite. In the area of the pivot lugs and the diagonal torque beams, titanium is used exclusively because of the complex loading. The main carry-through beam utilized boron-aluminum composite as the cap material on a titanium carrier beam.

3.1.3.4 Thrust Structure - Thrust structure on the vehicle is a conical shaped, integrally stiffened shell of boron-aluminum composite. The two main boost engines are approximately in line with the integral propellant tank structure and this conical structural shell transfers engine thrust loads to the tank walls. The thrust structure concept is similar to the integral tank shell with integral logitudinal stiffeners spaced 2.0 to 3.0 inches apart. Longitudinal stiffeners are located on the inner cone surface and are terminated at various intervals due to the decreasing diameter of the thrust cone approaching the apex. Stiffening rings, located on the outer cone surface, comprised of an integral inner flange on the shell and a mechanically attached outer flange cap and web.

3.1.3.5 Aft Bulkhead Design - The vehicle aft bulkhead frame is composed of beams and shear panels. Beam caps are unidirectional boron-aluminum and shear panels are titanium alloy. This bulkhead is attached to the rectangular area of the propellant tank transition section. The bulkhead contains three ground handling sockets for vehicle erection and handling, plus two stage tie points. The lower frame of the aft bulkhead extends outboard and forms the main spar for the fixed fins as well as providing hinge lugs for the lower elevons and hypersonic flap. Also contained in this bulkhead at the outboard sides are the left and right movable upper fin bearing assemblies. Finally, a shroud or fairing attached to the two rearward openings provide maximum protection and seal for the two boost engines.

3.1.4 Thermal Protection System - The thermal protection system consists of high temperature metallic shingles on the outside backed with blankets of low density insulation. Figure 3-57 depicts the type of materials forming the exterior skin. TD nickel chrome shingles covers most of the bottom surface area except for a small area near the nose cap where coated columbium is used. Composites of boron-titanium or boron-aluminum are employed on the vehicle sides and upper surfaces where lower temperatures exist. The nose cap and leading edges are made from a carbon-carbon composite. All of the exterior surface materials, except for the carbon-carbon parts, are designed for a re-use capability of 100 flights. The life span of the carbon parts is being extended by the addition of oxidation inhibitors. Recent tests indicate that somewhere between 4 to 10 flights can be made before refurbishment is required. It is anticipated that additional work in this area will greatly extend the reuse capability of the carbon-carbon composite.

CONCEPT "S" THERMAL PROTECTION SYSTEM MATERIALS

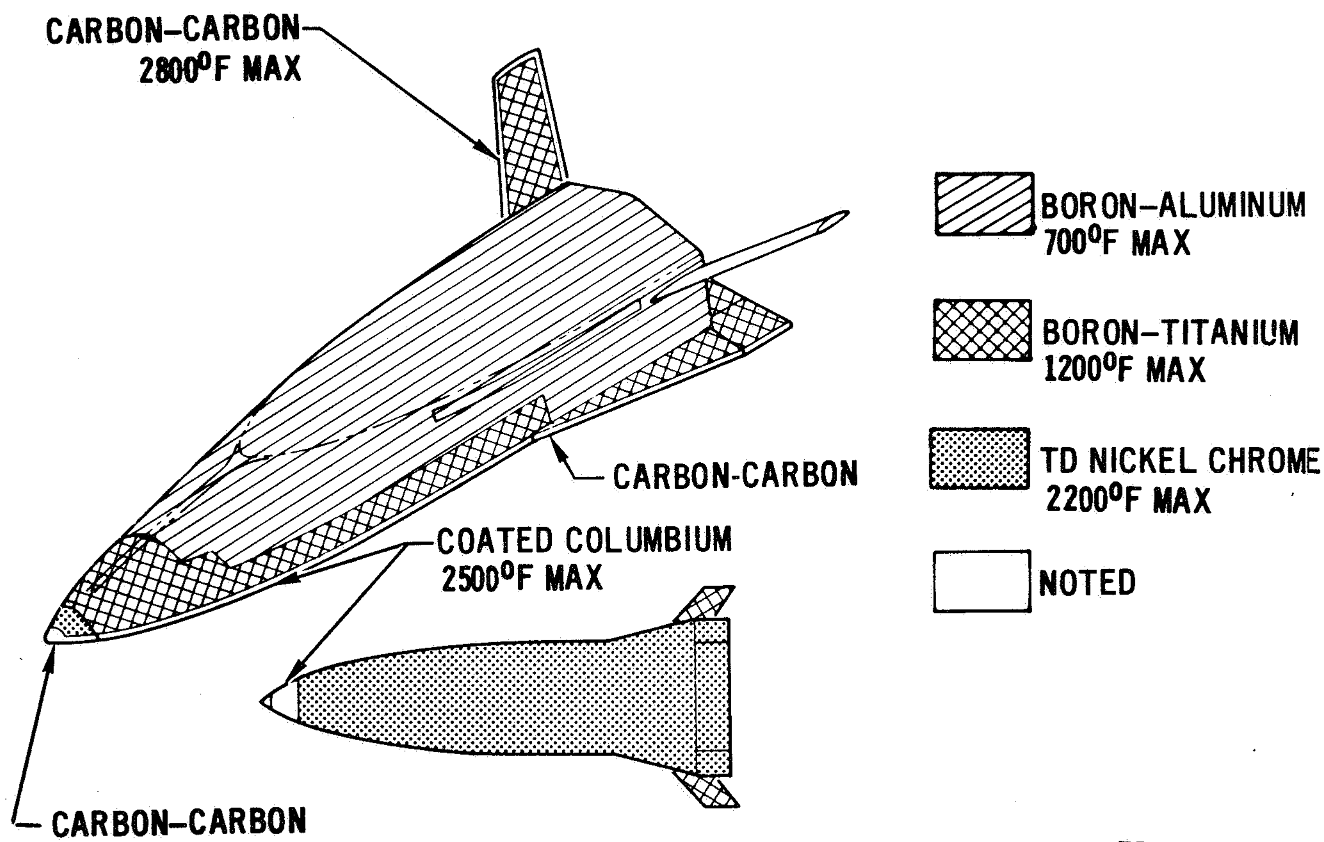


FIGURE 3-57

Blankets of low density fibrows insulation (3.5 lb/ft^3 microquartz) are provided directly in back of the high temperature shingle. The thickness of insulation is sized to limit the propulsion tank wall temperature to 200°F.

The baseline radiative heat shield panels are supported on structural trusses and frames. These frames, which define the body cross section, are positioned by tubular support struts (Figure 3-56) located between the frames and the load carrying integral propellant tanks. Vertical frame orientation is maintained by drag struts which carry inertia loads from frames and panels due to longitudinal acceleration. Vehicle centerline reference points on the bottom frame are located by triangular truss structure supported from the integral tanks. Frames on either side of the fixed center points are permitted to expand due to thermal elongation. Additional tubular members, attaching the bottom surface frames to the tank structure, form a stable four bar linkage. Tubular members are arranged so that panel loads are applied tangentially to the tank structure. In a similar manner, upper body fixed points are formed by the intersection of two struts mounted to the tank sides. Similar tubular struts locate frames around the wing deployment door opening and provide wing doors a fixed seal surface. Side frames, similar to the bottom frames, extend downward from this stationary point to intersect the bottom frames and complete the framing geometry. Body side support struts carry normal panel loads and are tangentially attached to the tank. They are free to pivot as required with side frame thermal elongation. The actual panel mold line is therefore determined by the thermal growth position of the bottom and side frames.

This geometry is repeated at 36 inch body station intervals (or as may be required around doors, etc.). Air loads and temperatures on the lower heat shield panels require intermediate transverse beams spaced midway between the principal transverse frames. These panels are 18 inches long in the direction of corrugations and 36 inches wide. Side heat shield panels are 36 inches by 36 inches. This type of construction is employed throughout the vehicle except in the forward body area forward of the nose gear. No assessment has been made of the total number of different size panels required to fit the body shape.

Installation requirements for landing engines, jet fuel, crew compartment and equipment storage areas resulted in selection of typical skin/stringer construction on the forward body. Maximum volume is obtained by locating the inner wall virtually adjacent to the TPS. In these regions tubular struts are not used and the TPS transfers air loads directly to circumferential rings in the forward body section.

3.1.5 Propulsion Systems - The propulsions systems required on the core vehicles include: (1) a boost propulsion, (2) attitude control, and (3) cruise or landing assist propulsion; and an orbit maneuvering system for the orbiter.

Since the basic core vehicles for this study were based on the use of the orbiter vehicle as defined in a recent study conducted by McDonnell Douglas for SAMSO/AFSC specific propulsion system information is "classified" and as such cannot be discussed in this document. For detailed information the reader is referred to Reference 1.

In general, the basic core vehicle propulsion systems are those depicted in Figure 3-58. The system contains 12 engines located approximately at the midpoint of the vehicle and 10 engines located aft for attitude control. The three jet engines, shown in the stowed position facing aft, are used for cruise back capability in the case of the booster and for landing assist on the orbiter. Upon engine deployment the center line engine, swings up into position and the two forward engines rotate outward. The two large propellant tanks and one small tank provide the necessary propellant (liquid O_2 and H_2) for the two boost engines.

For the purposes of this study the option existed to extend the small propellant tank forward through the payload bay thereby making an integral tank

CONCEPT "S"
CORE STAGE PROPULSION

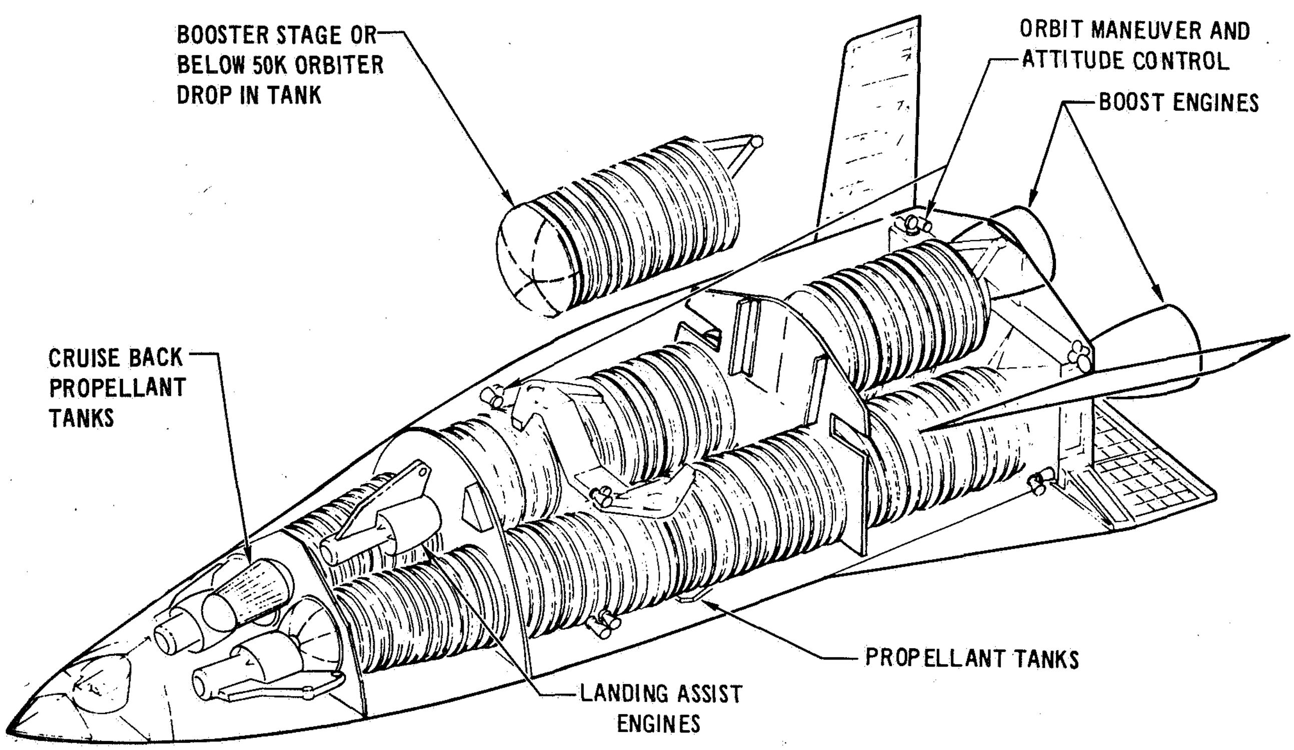


FIGURE 3-58

for that core vehicle serving as a booster. However, with an eye towards maximum orbiter/booster commonality, a drop-in tank was sized to fill the unused payload volume in order to increase the overall system performance. Likewise drop-in tanks were also used in the orbiter for the 12,500 and 25,000 lb payload cases in lieu of payload for the remaining volume capability.

Details as to the zero stage descriptions have already been discussed in the Sizing and Performance Analysis, Section 3.1.2.3.

3.1.6 Weight Analysis - The purpose of this section of the report is to present the detailed weight estimates generated for each of the configurations analyzed during this phase of the study. Each configuration consisted of an orbiter, booster and a number of zero stages. The zero stages were either solid or liquid and either expendable or reusable. Since the orbiter and booster are essentially identical stages, for any one configuration except for the cross feed systems and payload volume utilization, they have the same dry weight. Weight estimates were generated for three payloads sizes (i.e., 12,500, 25,000, and 50,000 lb) for three different configurations. These configurations include (1) a constant length (165 feet) orbiter and booster, (2) a constant ΔV orbiter equal to 18,790 fps and (3) a constant ΔV orbiter equal to 20,890 fps.

Since the orbiter and booster are essentially alike, weights were governed by the design of the subsystems capable of performing either orbiter or booster functions. For example, the booster would normally require smaller landing assist engines and a larger fuel tank than the orbiter. In order to maintain commonality a set of orbiter designed engines and a booster designed fuel tank was combined into one system for both stages. Jet fuel was added only as necessary for the fulfillment of each vehicle mission.

Weight summaries for each of the configurations analyzed are presented in Tables 3-5 through 3-11. The component weight breakdown logic used in the analysis is shown in Figure 3-59. This format was used in determining the weights of the various components for the baseline configuration (i.e., orbiter/booster length equal to 165 feet). In the case of the two constant ΔV orbiter configurations (i.e., ΔV = 18,790 and 20,890 fps) weights were broken down only to the subsystem level.

Tables 3-5 and 3-6 summarize the weight statements for the baseline configuration. Table 3-5 presents individual lift-off weights for the zero stages, orbiter and booster as well as the total gross launch weight of the entire

TABLE 3-5

CONCEPT "S" – TOTAL GROSS LAUNCH WEIGHT SUMMARY – ORBITER/BOOSTER LENGTH 165 FT

CONFIGURATION	50K PAYLOAD		25K PAYLOAD		12.5K PAYLOAD	
	EXPENDABLE ZERO STAGE	REUSABLE ZERO STAGE	EXPENDABLE ZERO STAGE	REUSABLE ZERO STAGE	EXPENDABLE ZERO STAGE	REUSABLE ZERO STAGE
LIQUID ZERO STAGES:	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
ZERO STAGE BURNOUT WEIGHT	540,218	619,628	382,332	434,558	320,514	363,020
ZERO STAGE PROPELLANT WEIGHT	3,390,860	3,492,440	2,303,960	2,351,560	1,876,220	1,908,326
ZERO STAGE LIFT-OFF WEIGHT	3,931,078	4,112,068	2,686,292	2,786,118	2,196,734	2,271,346
ORBITER LIFT-OFF WEIGHT	1,297,880	1,297,880	1,365,550	1,365,550	1,407,730	1,407,730
BOOSTER LIFT-OFF WEIGHT	1,509,350	1,509,350	1,490,310	1,490,310	1,482,090	1,482,090
GROSS LAUNCH WEIGHT	6,738,308	6,919,298	5,542,152	5,641,978	5,086,554	5,161,166
SOLID ZERO STAGES:						
ZERO STAGE BURNOUT WEIGHT	628,492	704,200	496,724	556,032	445,108	498,404
ZERO STAGE PROPELLANT WEIGHT	3,455,568	3,552,980	2,392,944	2,448,000	1,976,684	2,017,944
ZERO STAGE LIFT-OFF WEIGHT	4,084,060	4,257,180	2,889,668	3,004,032	2,421,792	2,516,348
ORBITER LIFT-OFF WEIGHT	1,297,880	1,297,880	1,365,550	1,365,550	1,407,730	1,407,730
BOOSTER LIFT-OFF WEIGHT	1,509,350	1,509,350	1,490,310	1,490,310	1,482,090	1,482,090
GROSS LAUNCH WEIGHT	6,891,290	7,064,410	5,745,528	5,859,892	5,311,612	5,406,168

Optimized Cost/Performance Design Methodology

TABLE 3-6 CONCEPT "S" GEOMETRICAL, MATERIAL AND SYSTEM DESCRIPTION DATA – ORBITER/BOOSTER LENGTH 165 FT

SUBSYSTEM/COMPONENT (LB)	50K PAYLOAD		25K PAYLOAD		12.5 PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
LENGTH – FT	165	165	165	165	165	165
PAYLOAD CYLINDER DIMENSIONS – FT	15 DIA x 60		15 DIA x 30		15 DIA x 15	
AREAS – SQ FT						
BODY WETTED AREA – OML	18,410	18,410	18,410	18,410	18,410	18,410
EMPENNAGE WETTED AREA						
UPPER TAILS	2,140	2,140	2,140	2,140	2,140	2,140
FIXED FINS	702	702	702	702	702	702
ELEVONS	604	604	604	604	604	604
HYPERSONIC FLAP	1,104	1,104	1,104	1,104	1,104	1,104
VG WING WETTED AREA	1,686	1,686	1,686	1,686	1,686	1,686
DOOR AREAS	2,767	2,767	2,767	2,767	2,767	2,767
VOLUME – CU FT						
BODY – OML	126,900	126,900	126,900	126,900	126,900	126,900
BODY STRUCTURE – WEIGHT (LB)	(67,120)	(67,120)	(67,120)	(67,120)	(67,120)	(67,120)
ALUMINUM	25,264	25,264	25,264	25,264	25,264	25,264
BORON-ALUMINUM	41,856	41,856	41,856	41,856	41,856	41,856
THERMAL PROTECTION SYSTEM – RADIATIVE						
BODY – WEIGHT (LB)/AREA (SQ FT)						
CARBON-CARBON	56/8	56/8	56/8	56/8	56/8	56/8
COLUMBIUM	261/90	261/90	261/90	261/90	261/90	261/90
TD NICKEL	15,351/6,417	15,351/6,417	15,351/6,417	15,351/6,417	15,351/6,417	15,351/6,417
BORON-TITANIUM	2,808/2,956	2,808/2,956	2,808/2,956	2,808/2,956	2,808/2,956	2,808/2,956
BORON-ALUMINUM	5,158/7,586	5,158/7,586	5,158/7,586	5,158/7,586	5,158/7,586	5,158/7,586
COLUMBIUM (LEADING EDGE)	1,828/213	1,828/213	1,828/213	1,828/213	1,828/213	1,828/213
MICROQUARTZ	13,267/17,270	13,267/17,270	13,267/17,270	13,257/17,270	13,267/17,270	13,267/17,270
ENCASEMENT	4,094/17,270	4,094/17,270	4,094/17,270	4,094/17,270	4,094/17,270	4,094/17,270
HCF	1,482/1,140	1,482/1,140	1,482/1,140	1,482/1,140	1,482/1,140	1,482/1,140
TYPICAL BOTTOM PANEL SIZE – FT	1.5 x 3	1.5 x 3	1.5 x 3	1.5 x 3	1.5 x 3	1.5 x 3
TYPICAL SIDE AND TOP PANEL SIZE – FT	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3
EMPENNAGE – WEIGHT (LB)/AREA (SQ FT)						
TD NICKEL	2,205/1,205	2,205/1,205	2,205/1,205	2,205/1,205	2,205/1,205	2,205/1,205
EMPENNAGE – WEIGHT (LB)/WETTED AREA (SQ FT)						
CARBON-CARBON	1,153/748	1,153/748	1,153/748	1,153/748	1,153/748	1,153/748
BORON-TITANIUM	15,840/4,302	15,840/4,302	15,840/4,302	15,840/4,302	15,840/4,302	15,840/4,302
VG WING – WEIGHT (LB)						
WING						
TITANIUM	10,871	10,871	10,871	10,871	10,871	10,871
BORON-ALUMINUM	9,202	9,202	9,202	9,202	9,202	9,202
CARRY-THRU STRUCTURE						
TITANIUM	1,831	1,831	1,831	1,831	1,831	1,831
BORON-ALUMINUM	1,346	1,346	1,346	1,346	1,346	1,346
MAIN PROPULSION						
TANK BULKHEADS AND BAFFLES						
ALUMINUM – WEIGHT (LB)/AREA (SQ FT)	5,031/1,338	5,031/1,338	5,031/1,338	5,031/1,338	5,031/1,338	5,031/1,338
BORON-ALUMINUM – WEIGHT (LB)/AREA (SQ FT)	470/745	470/745	470/745	470/745	470/745	470/745
TANK INSULATION						
POLYURETHANE FOAM – WEIGHT (LB)/AREA (SQ FT)	3,499/8,858	3,499/8,858	3,499/8,858	3,499/8,858	3,499/8,858	3,499/8,858
THRUST STRUCTURE						
BORON-ALUMINUM – WEIGHT (LB)	1,870	1,870	1,870	1,870	1,870	1,870
DROP IN TANK						
ALUMINUM – WEIGHT (LB)/AREA (SQ FT)		460/861	460/861	460/861	460/861	460/861
BORON-ALUMINUM – WEIGHT (LB)/AREA (SQ FT)	–	1,470/2,328	580/914	1,470/2,328	1,020/1,621	1,470/2,328
POLYURETHANE FOAM – WEIGHT (LB)/AREA (SQ FT)	–	860/2,176	450/1,149	860/2,176	660/1,667	860/2,176
VOLUME – CU FT		9,978	4,676	9,978	7,327	9,978
ENGINE DESCRIPTION						
TYPE	HIGH PC BELL	HIGH PC BELL	HIGH PC BELL	HIGH PC BELL		HIGH PC BELL
NUMBER	2	2	2	2	2	2
THRUST PER ENGINE – LB (VAC)	973,000	973,000	973,000	973,000	973,000	973,000
PROPELLANT TYPE	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
ORBIT MANEUVER SYSTEM						
TANK						
BORON-ALUMINUM – WEIGHT (LB)	940	940	870	870	840	840
HPI – WEIGHT (LB)	390	390	360	360	350	350
VOLUME – CU FT	2,520	2,520	2,340	2,340	2,250	2,250
PROPELLANT TYPE	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
ATTITUDE CONTROL SYSTEM						
TANK						
BORON-ALUMINUM – WEIGHT (LB)	250	250	230	230	220	220
VOLUME – CU FT	76	76	73	73	71	71
ENGINE DESCRIPTION						
TYPE	← SINGLE-PASS REGENERATIVE/DUMP COOLED →					
NUMBER	22	22	22	22	22	22
THRUST PER ENGINE – LB (VAC)	3,440	3,440	3,190	3,190	3,070	3,070
PROPELLANT TYPE	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2
LANDING ASSIST						
TANK – BLADDER TYPE						
VOLUME – CU FT	910	910	705	705	620	620
ENGINE DESCRIPTION						
TYPE	TURBOFAN	TURBOFAN	TURBOFAN	TURBOFAN	TURBOFAN	TURBOFAN
NUMBER	3	3	3	3	3	3
THRUST PER ENGINE – LB (SLS)	51,100	51,100	47,400	47,400	45,600	45,600
FUEL TYPE	JP	JP	JP	JP	JP	JP
PRIME POWER SYSTEM						
BATTERIES (AgO-Zn)						
ENERGY PER BATTERY – KWH	6	6	6	6	6	6
NUMBER	2	2	2	2	2	2
FUEL CELL						
POWER OUTPUT PER FUEL CELL – KW	2.0–2.5	2.0–2.5	2.0–2.5	2.0–2.5	2.0–2.5	2.0–2.5
NUMBER	4	4	4	4	4	4
APU						
NUMBER	3	3	3	3	3	3
ENVIRONMENTAL CONTROL SYSTEM						
NUMBER OF CREW	2	2	2	2	2	2
MISSION DURATION – DAYS			7	7	7	7

TABLE 3-7

CONCEPT "S" – ORBITER AND BOOSTER WEIGHT SUMMARY
ORBITER/BOOSTER LENGTH 165 FT

SUBSYSTEM/COMPONENT (LB)	50K PAYLOAD		25K PAYLOAD		12.5K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
BODY STRUCTURE	(67,120)	(67,120)	(67,120)	(67,120)	(67,120)	(67,120)
INTEGRAL TANK SIDEWALLS	21,583	21,583	21,583	21,583	21,583	21,583
REMAINING BODY STRUCTURE	45,537	45,537	45,537	45,537	45,537	45,537
THERMAL PROTECTION SYSTEM	(46,510)	(46,510)	(46,510)	(46,510)	(46,510)	(46,510)
BODY	42,823	42,823	42,823	42,823	42,823	42,823
AERO SURFACES	2,205	2,205	2,205	2,205	2,205	2,205
BASE HEAT SHIELD	1,482	1,482	1,482	1,482	1,482	1,482
AERO SURFACES	(39,090)	(39,090)	(39,090)	(39,090)	(39,090)	(39,090)
VG WING	23,250	23,250	23,250	23,250	23,250	23,250
UPPER TAILS	8,250	8,250	8,250	8,250	8,250	8,250
FIXED FINS	2,210	2,210	2,210	2,210	2,210	2,210
ELEVONS	1,900	1,900	1,900	1,900	1,900	1,900
HYPERSONIC FLAP	3,480	3,480	3,480	3,480	3,480	3,480
LANDING GEAR	(12,390)	(12,390)	(11,470)	(11,470)	(11,050)	(11,050)
MAIN PROPULSION SYSTEM	(46,530)	(52,490)	(48,400)	(52,490)	(49,210)	(52,490)
ENGINES	17,900	17,900	17,900	17,900	17,900	17,900
GIMBALS	2,700	2,700	2,700	2,700	2,7000	2,700
TANK BULKHEADS AND BAFFLES	5,501	5,501	5,501	5,501	5,501	5,501
H_2 TANK INSULATION	3,499	3,499	3,499	3,499	3,499	3,499
THRUST STRUCTURE	1,870	1,870	1,870	1,870	1,870	1,870
FEED SYSTEM	15,060	17,630	15,060	17,630	15,060	17,630
DROP IN TANK	–	3,390	1,870	3,390	2,680	3,390
ORBIT MANEUVER SYSTEM	(6,050)	(6,050)	(5,600)	5,600)	(5,400)	(5,400)
TANK	940	940	870	870	840	840
INSULATION	390	390	360	360	350	350
LINES, VALVES, PRESS, ETC.	2,990	2,990	2,770	2,770	2,660	2,660
MOUNTING STRUCTURE	1,730	1,730	1,600	1,600	1,550	1,550
ATTITUDE CONTROL SYSTEM	(3,890)	(3,890)	(3,600)	(3,600)	(3,470)	(3,470)
ENGINES	750	750	690	690	670	670
TANK	250	250	230	230	220	220
ACCUMULATORS	970	970	900	900	860	860
COMPRESSORS	540	540	500	500	490	490
LINES, VALVES, PRESS, ETC.	680	680	630	630	610	610
MOUNTING STRUCTURE	700	700	650	650	620	620
LANDING ASSIST	(31,250)	(31,250)	(28,600)	(28,600	(27,400)	(27,400)
ENGINES	25,160	25,160	23,270	23,270	22,410	22,410
FUEL TANK	890	890	690	690	610	610
FEED SYSTEM	1,340	1,340	1,040	1,040	910	910
ENGINE INSTALLATION	760	760	700	700	670	670
MOUNTING STRUCTURE	3,100	3,100	2,900	2,900	2,800	2,800
PRIME POWER SYSTEM	(4,700)	(4,700)	(4,700)	(4,700)	(4,700)	4,700)
BATTERIES	230	230	230	230	230	230
FUEL CELLS	400	400	400	400	400	400
REACTANT SUBSYSTEM – DRY	327	327	327	327	327	327
REACTANTS (H_2–O_2)	765	765	765	765	765	765
AUXILIARY POWER UNIT	330	330	330	330	330	330
FUEL	907	907	907	907	907	907
TANKS, LINES AND VALVES	100	100	100	100	100	100
MOUNTING STRUCTURE	275	275	275	275	275	275
INVERTER	166	166	166	166	166	166
CIRCUITRY	1,206	1,206	1,206	1,206	1,206	1,206
HYDRAULICS	(1,667)	(1,667)	(1,667)	(1,667)	(1,667)	(1,667)
AERODYNAMIC CONTROLS	(3,073)	(3,073)	(3,073)	(3,073)	(3,073)	(3,073)
AVIONICS	(2,390)	(2,390)	(2,390)	(2,390)	(2,390)	(2,390)
GUIDANCE AND NAVIGATION	890	890	890	890	890	890
TELECOMMUNICATIONS	325	325	325	325	325	325
CENTRAL MANAGEMENT COMPUTER	180	180	180	180	180	180
DISPLAYS, CONTROLS AND SEQUENCING	480	480	480	480	480	480
FLIGHT CONTROL	75	75	75	75	75	75
CONTROL AMPLIFIERS	125	125	125	125	125	125
INSTRUMENTATION	125	125	125	125	125	125
MOUNTING STRUCTURE	190	190	190	190	190	190
ENVIRONMENTAL CONTROL SYSTEM	(1,450)	(1,450)	(1,450)	(1,450)	(1,450)	(1,450)
GAS MANAGEMENT AND PROCESSING	52	52	52	52	52	52
GAS SUPPLY AND CONTROLS	353	353	353	353	353	353
HEAT TRANSPORT	530	530	530	530	530	530
CREW WATER SUPPLY	11	11	11	11	11	11
HYDRAULIC SYSTEM COOLING	409	409	409	409	409	409
CIRCUITRY LINES, FITTINGS	95	95	95	95	95	95
CREW AND FURNISHINGS	(600)	(600)	(600)	(600)	(600)	(600)
CREW	400	400	400	400	400	400
FURNISHINGS	200	200	200	200	200	200
BALLAST	0	0	(540)	0	(1,680)	0
CONTINGENCY	(26,600)	(27,200)	(26,360)	(26,770)	(26,250)	(26,570)
MAIN PROPELLANT	(943,360)	(1,163,570)	(1,038,990)	(1,159,430)	(1,094,170)	(1,157,510)
USABLE – BOOST	883,300	1,147,430	981,680	1,143,380	1,038,020	1,141,510
ON ORBIT MANEUVER	49,220	–	45,570	–	43,890	–
RESIDUAL AND PRESSURANT	10,840	16,140	11,740	16,050	12,260	16,000
JET FUEL	(5,220)	(44,650)	(4,840)	(34,540)	(4,660)	(30,400)
USABLE	5,120	43,770	4,740	33,860	4,570	29,800
RESIDUAL	100	880	100	680	90	600
ACS PROPELLANT	(5,990)	(1,260)	(5,550)	(1,210)	(5,340)	(1,200)
USABLE	5,830	1,230	5,400	1,180	5,190	1,170
RESIDUAL	160	30	150	30	150	30
PAYLOAD	(50,000)	–	(25,000)	–	(12,500)	–
STAGE LIFT-OFF WEIGHT	1,297,880	1,509,350	1,365,550	1,490,310	1,407,730	1,482,090
ΔV – FPS	18,790*	7,730	20,675*	7,525	21,675*	7,395

*INCLUDES 2000 FPS ON-ORBIT ΔV

TABLE 3-8

CONCEPT "S" – TOTAL GROSS LAUNCH WEIGHT SUMMARY – ORBITER $\Delta V = 18{,}790$ FPS*

CONFIGURATION	50K PAYLOAD EXPENDABLE ZERO STAGE	50K PAYLOAD REUSABLE ZERO STAGE	25K PAYLOAD EXPENDABLE ZERO STAGE	25K PAYLOAD REUSABLE ZERO STAGE	12.5K PAYLOAD EXPENDABLE ZERO STAGE	12.5K PAYLOAD REUSABLE ZERO STAGE
LIQUID ZERO STAGES:	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
ZERO STAGE BURNOUT WEIGHT	540,218	619,628	505,730	573,106	364,436	568,044
ZERO STAGE PROPELLANT WEIGHT	3,390,860	3,492,440	3,210,940	3,334,700	3,141,000	3,265,860
ZERO STAGE LIFT-OFF WEIGHT	3,931,078	4,112,068	3,716,670	3,907,806	3,505,436	3,833,904
ORBITER LIFT-OFF WEIGHT	1,297,880	1,297,880	1,062,530	1,062,530	941,930	941,930
BOOSTER LIFT-OFF WEIGHT	1,509,350	1,509,350	1,179,410	1,179,410	1,011,090	1,011,090
GROSS LAUNCH WEIGHT	6,738,308	6,919,298	5,958,610	6,149,746	5,458,456	5,786,924
SOLID ZERO STAGES:						
ZERO STAGE BURNOUT WEIGHT	628,492	704,200	607,964	683,784	605,044	682,476
ZERO STAGE PROPELLANT WEIGHT	3,455,568	3,552,980	3,290,040	3,401,368	3,266,480	3,391,600
ZERO STAGE LIFT-OFF WEIGHT	4,084,060	4,257,180	3,898,004	4,085,152	3,871,524	4,074,076
ORBITER LIFT-OFF WEIGHT	1,297,880	1,297,880	1,062,530	1,062,530	941,930	941,930
BOOSTER LIFT-OFF WEIGHT	1,509,350	1,509,350	1,179,410	1,179,410	1,011,090	1,011,090
GROSS LAUNCH WEIGHT	6,891,290	7,064,410	6,139,944	6,327,092	5,824,544	6,027,096

*INCLUDES 2,000 FPS ON ORBIT ΔV

TABLE 3-9

CONCEPT "S" – ORBITER AND BOOSTER WEIGHT SUMMARY – ORBITER $\Delta V = 18{,}790^*$ FPS

SUBSYSTEM (LB)	50 K PAYLOAD		25 K PAYLOAD		12.5 K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
BODY STRUCTURE	67,120	67,120	59,050	59,050	54,900	54,900
THERMAL PROTECTION SYSTEM	46,510	46,510	42,770	42,770	40,750	40,750
AERO SURFACES	39,090	39,090	35,090	35,090	33,060	33,060
LANDING GEAR	12,390	12,390	10,150	10,150	8,990	8,990
MAIN PROPULSION SYSTEM	46,530	52,490	38,530	42,960	34,380	37,890
ORBIT MANEUVER SYSTEM	6,050	6,050	4,960	4,960	4,390	4,390
ATTITUDE CONTROL SYSTEM	3,890	3,890	3,190	3,190	2,820	2,820
LANDING ASSIST	31,250	31,250	25,700	25,700	22,840	22,840
PRIME POWER SYSTEM	4,700	4,700	4,600	4,600	4,540	4,540
HYDRAULICS	1,667	1,667	1,440	1,440	1,350	1,350
AERODYNAMIC CONTROLS	3,073	3,073	2,660	2,660	2,490	2,490
AVIONICS	2,390	2,390	2,390	2,390	2,390	2,390
ENVIRONMENTAL CONTROL SYSTEM	1,450	1,450	1,450	1,450	1,450	1,450
CREW AND FURNISHINGS	600	600	600	600	600	600
BALLAST	0	0	0	0	0	0
CONTINGENCY	26,600	27,200	23,200	23,640	21,440	21,790
MAIN PROPELLANT	883,300	1,147,430	723,140	865,650	641,080	722,520
ON-ORBIT PROPELLANT	49,220	–	40,300	–	35,720	–
RESIDUAL	10,840	16,140	9,130	13,310	8,100	11,710
JET FUEL	5,220	44,650	4,280	38,700	3,790	35,600
ACS PROPELLANT	5,990	1,260	4,900	1,100	4,350	1,010
PAYLOAD	50,000	–	25,000	–	12,500	–
STAGE LIFT-OFF WEIGHT – (LB)	1,297,880	1,509,350	1,062,530	1,179,410	941,930	1,011,090
ΔV – (FPS)	18,790*	7,730	18,790*	7,180	18,790*	6,790
LENGTH – (FT)	165	165	158	158	155	155

* INCLUDES 2000 FPS ON-ORBIT ΔV

TABLE 3-10

CONCEPT "S" – TOTAL GROSS LAUNCH WEIGHT SUMMARY – ORBITER ΔV = 20,890 FPS*

CONFIGURATION	50 K PAYLOAD		25 K PAYLOAD		12.5 PAYLOAD	
	EXPENDABLE ZERO STAGE (LB)	REUSABLE ZERO STAGE (LB)	EXPENDABLE ZERO STAGE (LB)	REUSABLE ZERO STAGE (LB)	EXPENDABLE ZERO STAGE (LB)	REUSABLE ZERO STAGE (LB)
LIQUID ZERO STAGES:						
ZERO STAGE BURNOUT WEIGHT	370,538	418,970	347,356	393,644	299,532	382,100
ZERO STAGE PROPELLANT WEIGHT	2,135,740	2,168,460	1,046,380	2,082,520	2,047,120	2,047,120
ZERO STAGE LIFT-OFF WEIGHT	2,506,278	2,587,430	2,393,736	2,476,164	2,346,652	2,429,220
ORBITER LIFT-OFF WEIGHT	1,805,950	1,805,750	1,497,560	1,497,560	1,339,390	1,337,370
BOOSTER LIFT-OFF WEIGHT	2,010,680	2,010,680	1,608,750	1,608,750	1,403,300	1,403,300
GROSS LAUNCH WEIGHT	6,322,908	6,404,060	5,500,046	5,582,474	5,089,342	5,171,910
SOLID ZERO STAGES:						
ZERO STAGE BURNOUT WEIGHT	455,628	508,968	450,272	503,916	449,060	503,248
ZERO STAGE PROPELLANT WEIGHT	2,061,524	2,096,192	2,018,312	2,059,084	2,008,544	2,054,076
ZERO STAGE LIFT-OFF WEIGHT	2,517,152	2,605,160	2,468,584	2,563,000	2,457,604	2,557,324
ORBITER LIFT-OFF WEIGHT	1,805,950	1,805,950	1,497,560	1,497,560	1,339,390	1,339,390
BOOSTER LIFT-OFF WEIGHT	2,010,680	2,010,680	1,608,750	1,608,750	1,403,300	1,403,300
GROSS LAUNCH WEIGHT	6,333,782	6,421,790	5,574,894	5,669,310	5,200,294	5,300,014

* INCLUDES 2,000 FPS ON-ORBIT ΔV

TABLE 3-11

CONCEPT "S" – ORBITER AND BOOSTER WEIGHT SUMMARY – ORBITER ΔV = 20,890* FPS

SUBSYSTEM (LB)	50K PAYLOAD		25K PAYLOAD		12.5K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
BODY STRUCTURE	83,570	83,570	73,430	73,430	68,460	68,460
THERMAL PROTECTION SYSTEM	52,740	52,740	48,700	48,700	46,510	46,510
AERO SURFACES	45,590	45,590	41,380	41,380	39,090	39,090
LANDING GEAR	14,960	14,960	12,400	12,400	11,090	11,090
MAIN PROPULSION SYSTEM	64,870	70,830	54,130	58,570	48,610	52,120
ORBIT MANEUVER SYSTEM	7,310	7,510	6,060	6,060	5,420	5,420
ATTITUDE CONTROL SYSTEM	4,700	4,700	3,890	3,890	3,480	3,480
LANDING ASSIST	37,130	37,130	30,870	30,870	27,650	27,650
PRIME POWER SYSTEM	4,900	4,900	4,780	4,780	4,700	4,700
HYDRAULICS	1,920	1,920	1,720	1,720	1,667	1,667
AERODYNAMIC CONTROLS	3,550	3,550	3,180	3,180	3,073	3,073
AVIONICS	2,390	2,390	2,390	2,390	2,390	2,390
ENVIRONMENTAL CONTROL SYSTEM	1,450	1,450	1,450	1,450	1,450	1,450
CREW AND FURNISHINGS	600	600	600	600	600	600
BALLAST	3,030	0	2,570	0	2,320	0
CONTINGENCY	32,510	33,100	28,440	28,880	26,380	26,730
MAIN PROPELLANT	1,305,670	1,581,010	1,082,720	1,235,080	967,970	1,058,540
ON-ORBIT PROPELLANT	59,400	–	49,260	–	44,040	–
RESIDUAL	16,130	21,430	13,370	17,550	11,960	15,560
JET FUEL	6,300	41,990	5,230	36,510	4,670	33,640
ACS PROPELLANT	7,230	1,510	5,990	1,310	5,360	1,210
PAYLOAD	50,000	–	25,000	–	12,500	–
STAGE LIFT-OFF WEIGHT (LB)	1,805,950	2,010,680	1,497,560	1,608,750	1,339,390	1,403,300
ΔV – FPS	20,890*	7,870	20,890*	7,455	20,890*	7,180
LENGTH – (FT)	176	176	169	169	165	165

*INCLUDES 2000 FPS ON-ORBIT ΔV

COMPONENT WEIGHT BREAKDOWN LOGIC

- BODY STRUCTURE
  - INTEGRAL TANK
  - FRAMES, BULKHEADS, ETC.
- THERMAL PROTECTION SYSTEM
  - BODY
  - AERO SURFACES
  - BASE HEAT SHIELD
- AERO SURFACES
  - WING
  - HORIZONTAL TAIL
  - VERTICAL TAIL
- LANDING GEAR
- MAIN PROPULSION SYSTEM
  - ENGINES
  - GIMBALS
  - TANK BULKHEADS & BAFFLES
  - TANK INSULATION
  - THRUST STRUCTURE
  - FEED SYSTEM
- ORBIT MANEUVER SYSTEM
  - ENGINES
  - TANK
  - LINES, VALUES, ETC.
- ATTITUDE CONTROL SYSTEM
  - ENGINES
  - TANK
  - LINES, VALUES, ETC.
- LANDING ASSIST
  - ENGINES
  - FUEL TANK
  - FEED SYSTEM
- PRIME POWER SYSTEM
  - BATTERIES
  - FUEL CELLS
  - REACTANT SUBSYSTEM-DRY REACTANTS
  - APU
    - FUEL
    - TANK,LINES, VALVES
  - MOUNTING STRUCTURE
  - INVERTER
  - CIRCUITRY
- HYDRAULIC
- AERODYNAMIC CONTROLS
- AVIONICS
  - GUIDANCE & NAVIGATION
  - TELECOMMUNICATIONS
  - CENTER MANAGEMENT COMPUTER
  - DISPLAYS,CONTROL & SEQUENCING
  - FLIGHT CONTROL
  - CONTROL AMPLIFIERS
  - INSTRUMENTATION
  - MOUNTING STRUCTURE
- ENVIRONMENTAL CONTROL SYSTEM
  - GAS MANAGEMENT & PROCESSING
  - GAS SUPPLY AND CONTROLS
  - HEAT TRANSPORT
  - CREW WATER SUPPLY
  - HYDRAULIC SYSTEM COOLING
  - AIR CYCLE
  - COOLANT LOOP
  - O_2 SUPPLY
  - CIRCUITRY, LINES, FITTINGS
- CREW & FURNISHINGS
  - CREW
  - FURNISHINGS
- BALLAST
- CONTINGENCY
- MAIN PROPELLANT
- ON-ORBIT PROPELLANT
- RESIDUALS AND PRESSURANT
- JET FUEL
  - USABLE
  - RESERVE
- ACS PROPELLANT
- PAYLOAD

FIGURE 3-59

system. Tradeoffs between solid versus liquid and expendable versus reusable zero stages are shown for each payload of interest.

Table 3-6 presents weight estimates for the orbiter and booster in accordance with the format of Figure 3-59. It should be noted that the majority of subsystems, with the exception of those dealing with propulsion, are held constant from payload to payload. Propulsion systems vary because the ΔV requirements for each payload configuration are different. The main boost engines were assumed to be the same for each payload case. An adjustment in zero stage thrust levels was required to maintain a constant T/W at liftoff. A drop-in propellant tank was added to the orbiter payload bay for the 12,500 and 25,000 lb configurations to fill the unused payload volume. Landing gear, landing assist, orbit maneuver and attitude control system weights reflect the drop-in tank and variable payload in the orbiter.

Table 3-7 serves several functions. First, it gives values for the various geometric parameters characterizing the vehicles such as length, area and volumes. Secondly, it presents a weight breakdown by material of the major hardware components and thirdly it gives a description of various systems in terms of type, quantity, power output, etc. The level of detail given in this table is commensurate with the requirements of the cost model.

Tables 3-8 and 3-9 present the weight statements for the case in which the orbiter ΔV capability was held to a constant value of 18,790 fps, while, Tables 3-10 and 3-11 present the same type data for the case in which the orbiter ΔV capability was held to a constant value of 20,890 fps. As noted previously the weights are given at the subsystem level. In addition to the weights, the respective ΔV capability and length of each core vehicle is given for each of the three payload variables. The majority of subsystems in these cases are held constant only for the orbiter and booster of a particular payload. Systems vary between payloads since each payload is associated with a different length vehicle.

3.2 Analysis of Concept "L" - The analysis of Concept "L" consisted of recording a set of basic study ground rules and assumptions (Section 3.2.1), providing detail descriptions of the major subsystems (Sections 3.2.2 through 3.2.5) and the generation of a detailed weight statement (Section 3.2.6). Discussions relative to each of these items is contained in this section of the report.

3.2.1 Ground Rules and Assumptions - The general ground rules and assumptions to the analysis of Concept "L" are listed below. Additional specific information relative to the core vehicles used in this concept can be found in Reference 2.

- Orbiter and booster stages same as those baseline configurations defined in NASA-LRC study under Contract NAS9-9204.
- Payload Considerations
  - 50,000 lb in a 15 ft dia., 60 ft long envelope
  - 25,000 lb in a 15 ft dia., 30 ft long envelope
  - 10,000 lb in a 15 ft dia., 17 ft long envelope
- High chamber pressure bell nozzles used for main propulsion system on both core vehicles
- Boost engines are the same size for both core stages for any one configuration.
- Boost propellants are LOX/LH_2
- Series burn with no propellant transfer between core stages
- On-orbit ΔV capability equal to 2000 fps
- Orbit maneuver and attitude control system propellant - GO_2/GH_2
- Landing assist engine - orbiter (turbojet), booster (turbofan)
- Nominal orbit attitude of 270 nautical miles and an inclination of 55°
- Insertion orbit of 45 x 100 nautical miles
- Mission duration - 7 days
- Both stages have a 2 man crew
- Crew will operate in a shirtsleeve environment
- Thermo-structural system designed to a 3g normal load factor and a 2200°F temperature limit
- Orbiter entry angle of attack equal to 50°
- Prime power for orbiter and booster is supplied respectively by H_2O_2 matrix type fuel cells and rechargeable AgO-2n batteries
- Three completely independent hydraulic subsystems

3.2.2 Concept Description

3.2.2.1 Orbiter - The structural concept and internal arrangement of the HL-10 second stage are shown in Figure 3-60.

The cargo bay shows the 15 ft. dia. 30 ft. long container with 1 ft. allowed at either end and on the diameter for installation clearance and mounting provisions. The boost propellant oxidizer tank is forward of the cargo and a hydrogen tank is on either side of, and aft of, the cargo. The walls of these tanks are made to conform to the inner moldline of the vehicle whenever possible. The tank walls then become the primary load carrying skin for vehicle loads. The inner moldline skin forms an extension of the tank walls forward of the oxygen tank, between oxygen and hydrogen tanks and aft of the hydrogen tanks.

The forward compartment encloses crew cabin, avionics, power supply, nose gear and landing propulsion system. The landing engines are deployed out the sides of the vehicle for operation. Additionally, a tunnel is provided between the crew cabin and cargo bay to permit transfer of the crew to a cargo container during orbit operations. This tunnel is inside the moldline and on the vehicle center line above the oxygen tank.

Propellant for 2000 fps in-orbit maneuvering capability is provided by two tanks below the forward portion of the cargo bay. The main landing gear is positioned on either side below the aft portion of the cargo bay. Thrust loads from the 2 boost engines are transferred to propellant tank walls/body skin by a lateral beam.

3.2.2.2 Booster - The structure and subsystems arrangement for the booster is shown in Figure 3-61. The planform view shows the external configuration on the right hand side of center line and the internal arrangement on the left side.

The vehicle body contains a dual lobe propellant tank with the oxidizer forward and the hydrogen in the aft portion. The walls of this tank form the primary structural skin for the vehicle body. The forward end of the body is formed by an extension of these tank walls and provide a transition to the nose radius. This volume encloses the crew cabin, avionics, power supply, and the nose gear. The aft end of the body, housing the boost engines, thrust structure, and propellant utilization system is also an extension of the propellant tanks. The lower surface boattail at the aft end, and the raised nose, provides a negative camber body. A center line web between the two tank lobes, body rings and stringers complete the body structure.

CONCEPT "L"
GENERAL ARRANGEMENT HL – 10

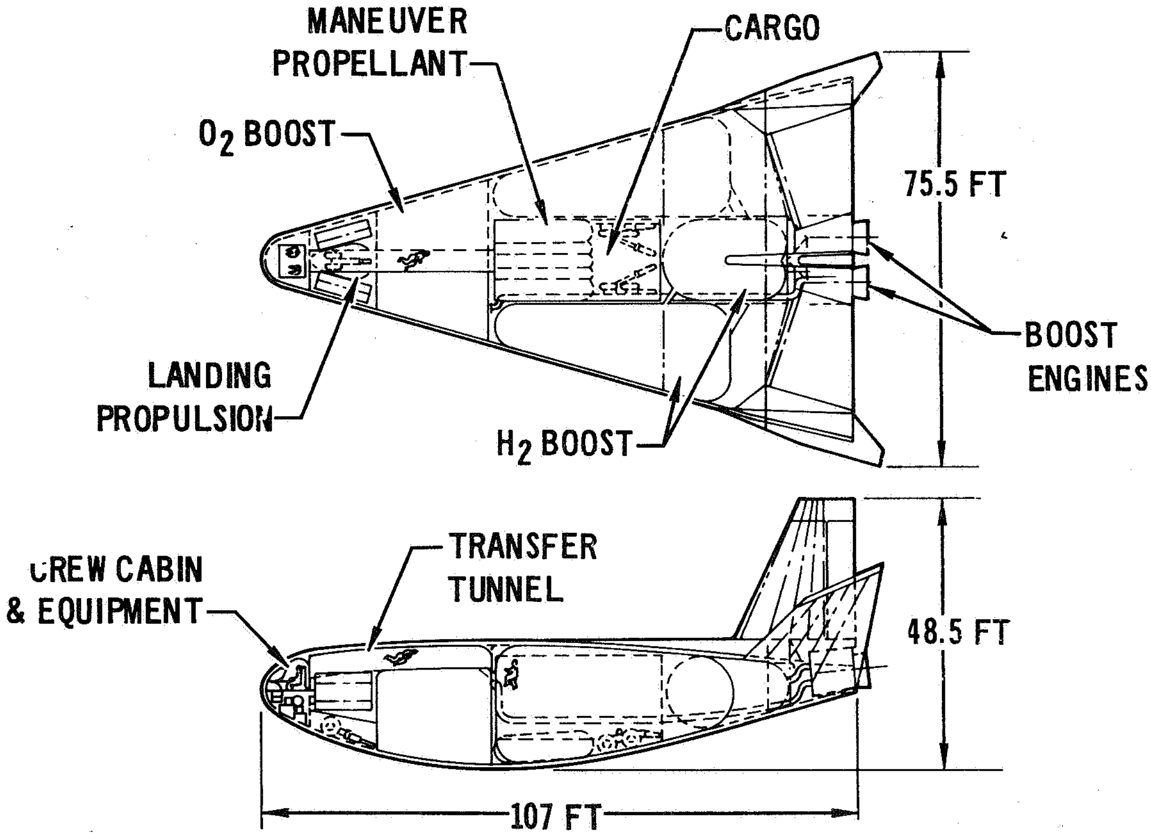


FIGURE 3-60

CONCEPT "L"
GENERAL ARRANGEMENT
CARRIER

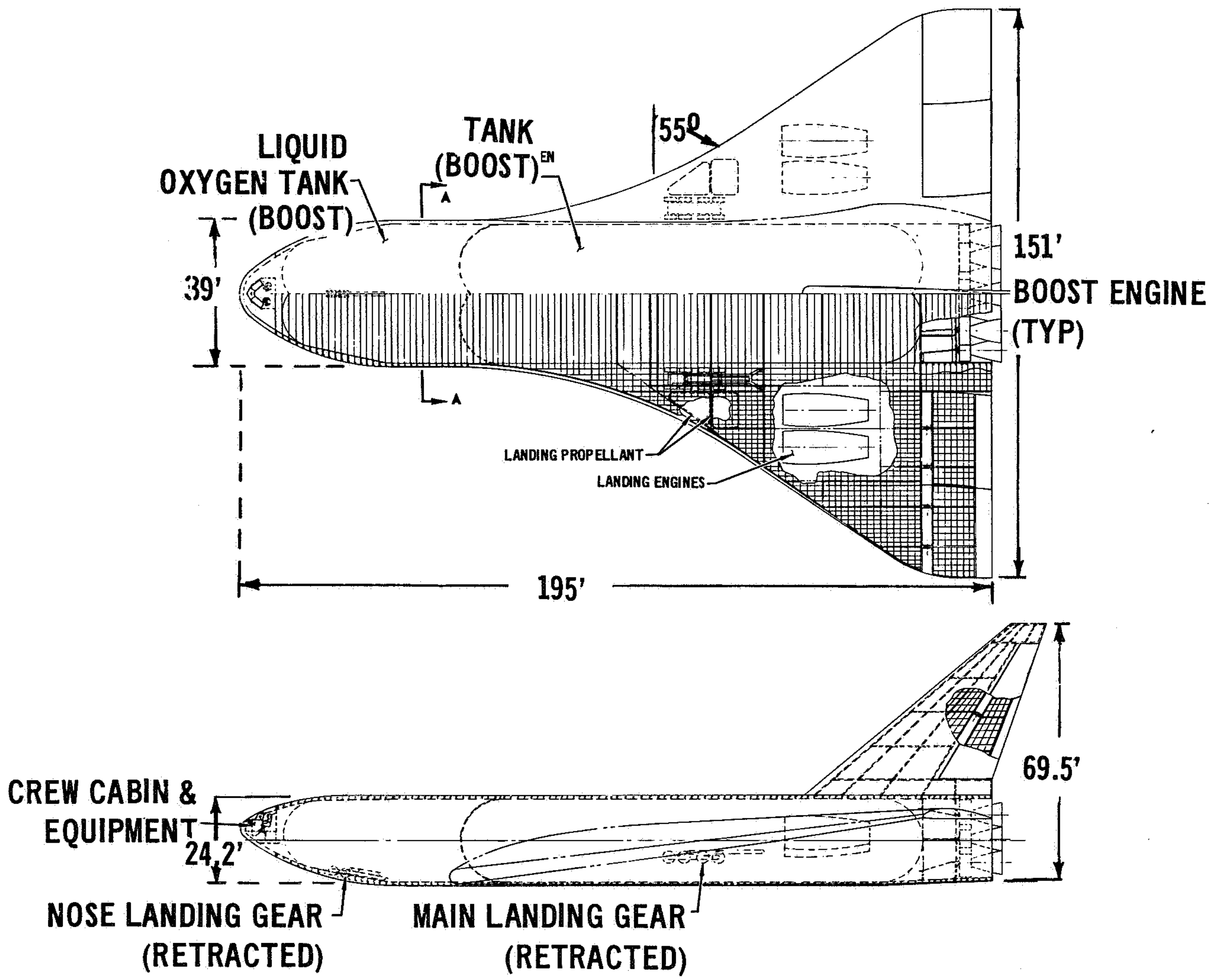


FIGURE 3-61

The wing conforms to a modified Clark Y airfoil. A thick wing and low wing position was selected. This permits enclosing the landing engines, landing propellant system, and main gear in the wing and eliminates the need for separate fairings on the body or wing to enclose these systems. The forward wing spar lies along a constant per cent of the chord. The other spars are normal to the body sides. This provides a transition to the body rings and a load path for wing carry-through without the necessity for penetrating the propellant tank walls with primary structure.

3.2.3 Structural Design - Included in this section is a description of the structure for both the orbiter and booster. Weight optimization was primary in design conception and choice of materials. Criteria and design loads generated were coordinated with the NASA-LRC Shuttle group. The spacecraft concept is a two stage vehicle with the orbiter being supported from the booster lifting body surface. A statically determinate three point attach arrangement is used for mating the two vehicles. The link at the aft attach point carries only direct tension or compression loads, all other loads are carried at the two forward attach points.

3.2.3.1 Orbiter Structure - The general arrangement of the orbiter airframe is shown in Figure 3-62. The body consists of an insulated aluminum shell structure with external moldline heat shield panels. Closure bulkheads are provided at the forward end of the payload bay and aft end of the body structure. The structural moldline is twelve inches inboard the external surface. For efficient utilization of available volume, the main propellant tanks are integrated with the shell structure to form irregular shaped pressure vessels. This integral tank structure provides load paths for carrying both body bending, axial and shear loads simultaneously with tank pressure loads. With the irregular shaped pressure vessel, pressure loads are distributed to bi-axially loaded internal baffle/webs by bending the sidewall stringers. The shell contains integral longitudinal stiffeners and lateral flanges for attachment of external frames. The pitch, depth and gauge of the longitudinal stiffeners and gauge of the skin are varied to meet local strength requirements. Spacing of frames supporting the non-structural heat shield panels and stiffening the shell varies from 12 to 15 inches. Frame outboard caps are made of titanium or René 41 depending on the local surface temperatures. Space between the inner and outer surface contains fibrous insulation with a minimum two inch void maintained for purging this space.

CONCEPT "L"

PICTORIAL FLOW CHART
Orbiter

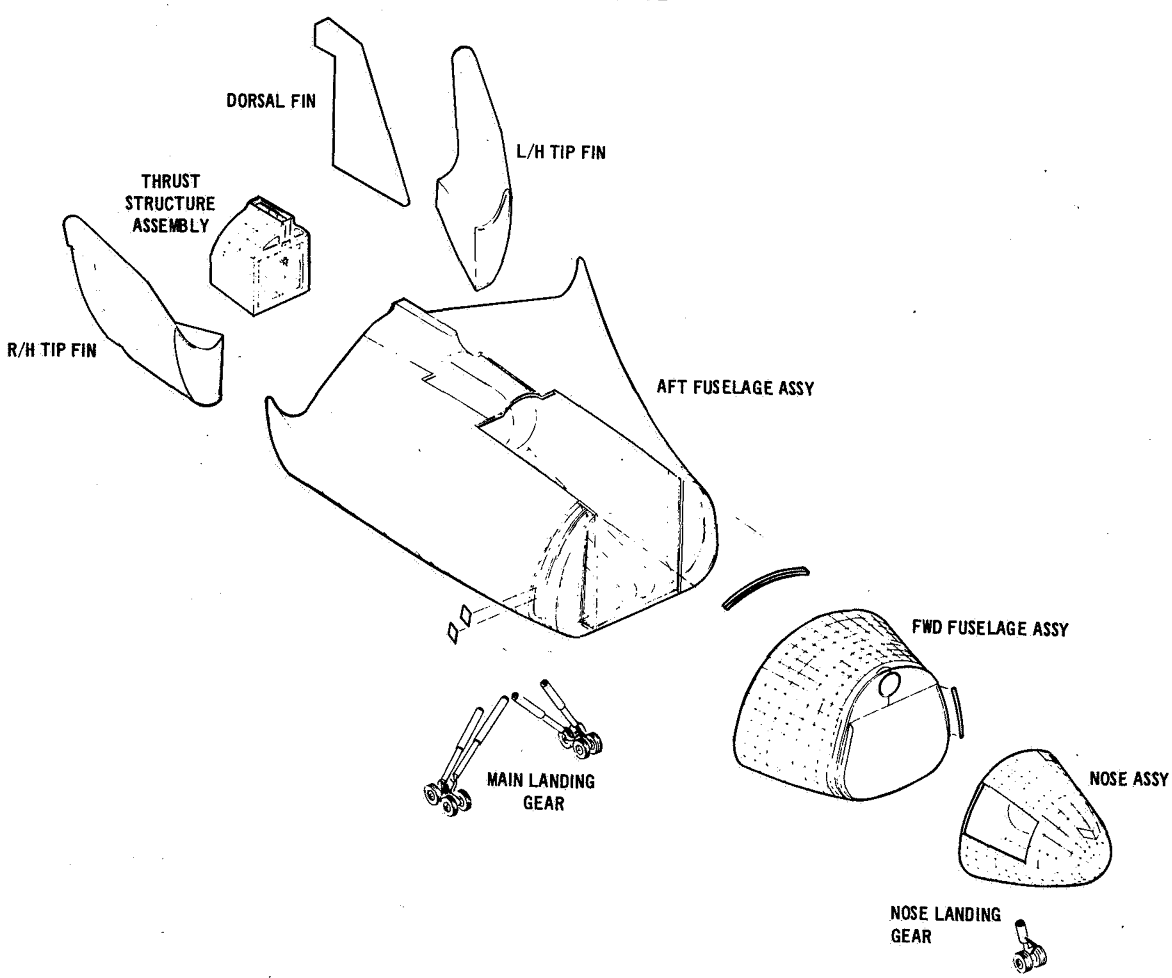


FIGURE 3-62

The closure bulkheads at the forward end of the payload bay and aft end of the body shell structure are utilized to redistribute vehicle/vehicle attach loads. Normal loads on the bulkheads are reacted by shears in the shell structure. Two titanium longerons are provided to distribute drag loads to the body structure. The upper attach points are located at the intersection of the payload bay side web and inner moldline web to take advantage of the multiple shear paths. The tip fins, elevons, and thrust structure are supported by the body shell and aft closure bulkhead. Torque boxes extending from the bulkhead support the tip fins. Thrust structure is extended from the two internal vertical web and enclosed moldline panels. The elevons are supported directly by the bulkhead and shell structure.

Heat shield panels (shingles) block the bulk of the heat from the aluminum body shell structure. Surface temperatures require the use of radiation cooled shingles of titanium, René 41, TD-NiCr and columbium alloy materials. Panel lengths vary from twelve to fifteen inches. Single thickness beaded panels are used on the upper shadowed surface in regions which experience low heating rates. Panels used on other areas of the body are composed of an external smooth skin stiffened by longitudinal corrugations. A pi shaped retainer reacts negative pressure loads from the corrugated panels and provides a gap for thermal expansion. Beaded panels are retained by round head screws with clamp-up bushings. Oversize holes provide for thermal expansion.

3.2.3.2 Booster Structure - The general arrangement of the booster airframe is shown in Figure 3-63. The airframe contains an insulated aluminum body shell structure with a titanium and René 41 wing and vertical tail structure.

The body consists of an integral tank structure with both the forward portion of the airframe and thrust structure being unpressurized extensions of this integral structure. The shell structure contains integral longitudinal stiffeners and lateral flanges for attachment of frames. The pitch, depth and gauge of the longitudinal stiffeners and gauge of the skin are varied to meet local strength requirements. The structural moldline is twelve inches inboard the external surface. Heat shield panels on the external surface are non-structural except for dynamic pressure loads and are attached so as to allow unrestrained thermal expansion. Frames supporting the heat shield panels and stiffening the shell are on twenty inch centers and are made of titanium to minimize conductance of heat to the inner structure. Space between the inner and outer surface contains

CONCEPT "L"
PICTORIAL FLOW CHART

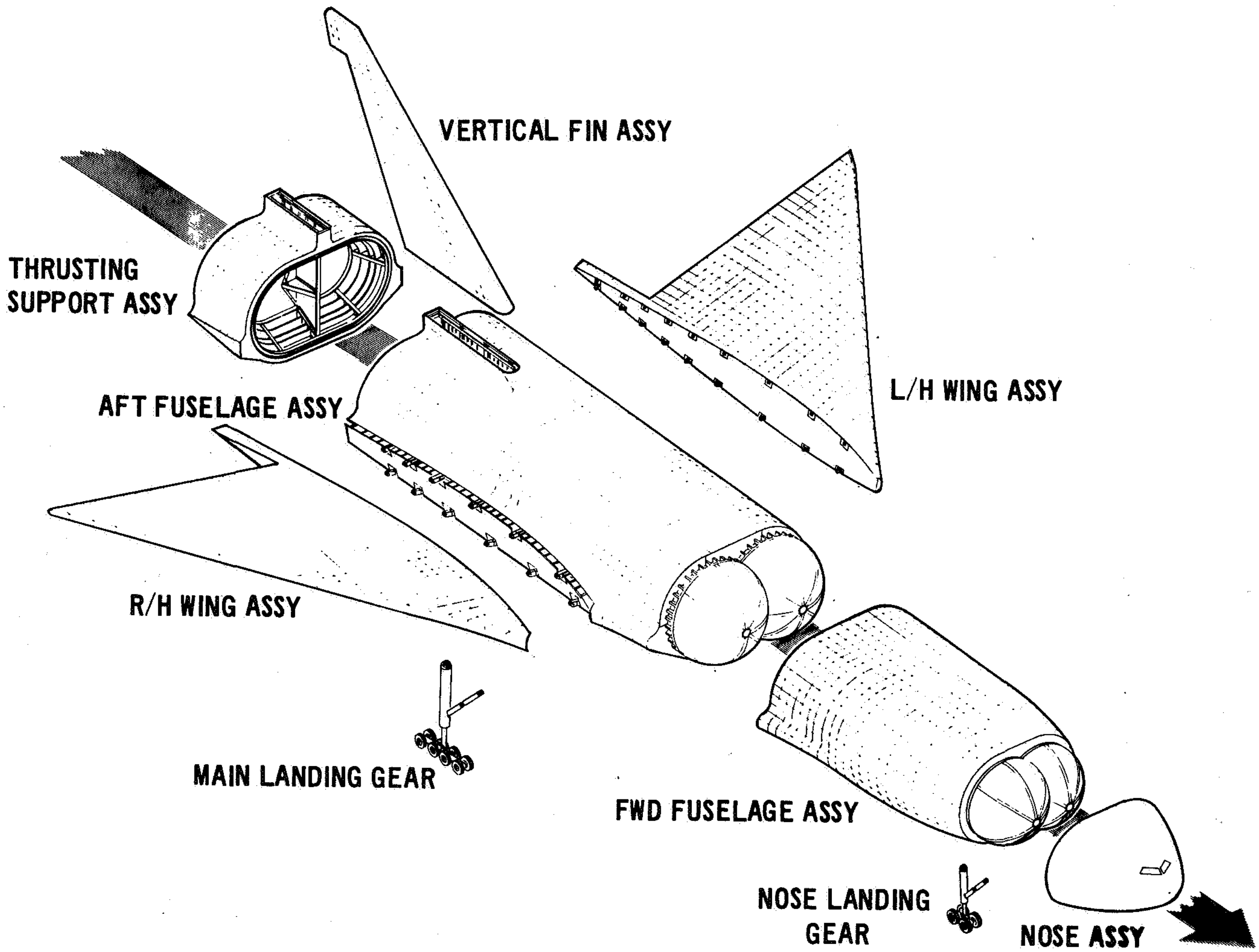


FIGURE 3-63

fibrous insulation with a minimum two inch void maintained for purging this space prior to launch.

The thrust structure consists of a semi-monocoque skirt, with a vertical keel web, extended from the integral tank structure, intercostals for local engine support and two major frames to support the intercostals. This arrangement leaves the center area open and easily accessible for installation of the propulsion system. Engine loads are reacted locally by the inboard intercostal cap and aft frame. Loads are sheared into the skirt and resulting kick loads are carried by the two major frames. Loads are then redistributed by the skirt and introduced into the integral tank structure as distributed loads. The basic structure as designed for thrust loads provides a capability for launch pad tie down loads. Launch pad attach points coincide with the intercostals at the lower frame. Tie down loads are reacted locally by the outboard intercostal caps and frame and are in turn distributed to the shell structure.

Structure provided for the vehicle/vehicle attach loads include attach fittings, major frames to react the normal loads and longerons to react the drag loads. At the forward attach points, an attach fitting extends outboard of the outer surface moldline with the interconnect inboard of the orbiter moldline. This external structure is fixed and made from René 41 alloy material because of reentry heating. Loads on the fittings are reacted by the frames and longerons. Normal loads on the frames are reacted by shears in the outer shell and centerline web. The required frame bending strength necessitates the addition of a beam cap inboard of the tank wall. Two titanium longerons are used to distribute drag loads to the integral body structure. The thrust structure is used to react the aft attach point loads.

The wing and tail are designed as hot structures. Design temperatures are such that René 41 and titanium alloy materials can be used for the structure. In general, René 41 material is used along the leading edges and forward portion of the lower wing surface with titanium material used over the remainder of the surfaces. Conventional multi-spar arrangements are used for both structures. Spars in the vertical tail have been located to coincide with wing carry through structure and thereby eliminate need for additional structural support members. Wing carry through structure at the rear spar is continuous through the thrust structure. Carry through structure at the intermediate and front spars is external to the integral tank structure. The wing/fuselage intersection is faired in the root area to provide efficient load path continuity between the two structures. The inboard frame cap is an integral part of the body structure. Titanium is used for the frame web and outboard cap because of its favorable strength weight ratio and to minimize conductance of heat to the inner structure.

Heat shield panels (shingles) block the bulk of the heat from the aluminum body shell structure. Surface temperatures permit the use of radiation cooled shingles of titanium and René 41 alloy materials. The panels are twenty inches long and on the lower surface and sides of the body are composed of an external smooth skin stiffened by longitudinal corrugations. Single thickness beaded panels are used on the upper shadowed surface in areas of low heating.

Panels distribute positive pressure loads directly to the frames by bearing on support channels. A pie shaped retainer reacts negative pressure loads from the corrugated panels and provides a gap for thermal expansion. Beaded panels are retained by round head screws with clamp-up bushings. Oversize holes provide thermal expansion.

3.2.4 Thermal Protection System

3.2.4.1 Orbiter TPS - The orbiter baseline exterior heat protection system consists of titanium shingles, René 41 shingles, TD nickel-chrome shingles, and columbium shingles distributed on the vehicle surface as shown in Figure 3-64. Titanium shingles are used on the upper body surface. René 41 shingles are used on the body sides, dorsal fin, upper elevon surfaces, and lower body surface near the orbiter centerline at the aft end. Columbium shingles are used on the body lower surface at the nose. TD nickel-chrome shingles are used on the body lower surface, lower elevon surfaces, tip fins, and dorsal fin leading edge.

Insulation will be required underneath the orbiter metallic shingles to reduce the heat transfer to the cryogenic tank wall in order that the temperature does not exceed 200°F.

An alternate orbiter configuration was considered using shingles constructed of HCF (hardened compacted fibers) in place of the TD nickel-chrome and columbium shingles. The same titanium and René 41 shingle configuration was used on each case. The TD nickel-crhome and columbium shingles proved superior to the HCF shingles on the basis of vehicle weight comparison.

CONCEPT "L"

MATERIAL DISTRIBUTION OF TPS SHINGLES HL-10

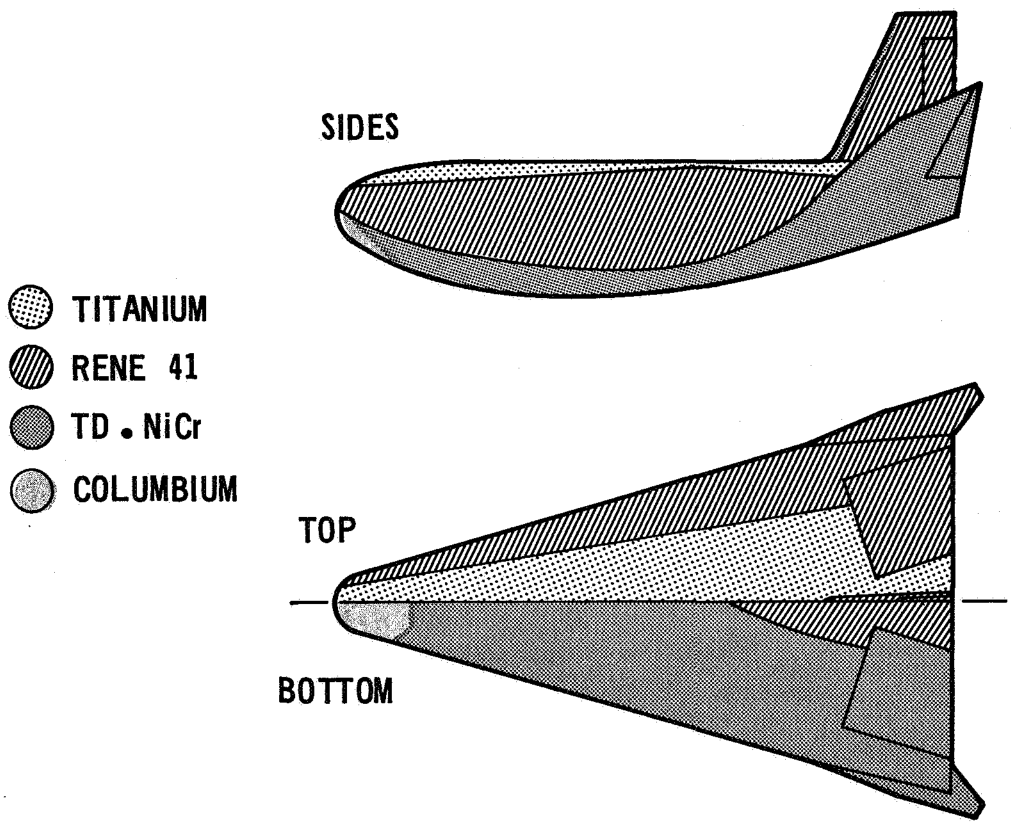


FIGURE 3-64

Although emphasis was placed in TD nickel-chrome during the study, it appears that columbium should be recommended because of the extensive experience acquired in fabrication, handling, and testing on the ASSET and BGRV programs. The radiative panels also permit more conventional manufacturing and handling techniques than the HCF which is more subject to damage requiring special handling and manufacturing processes.

Material selection is based on the following temperature use ranges:

Titanium (8Al-1Mo-1V)	400 - 1000°F
René 41	1000 - 1600°F
TD-NiCr	1600 - 2200°F
Columbium	2200 - 2800°F

The temperature use range upper bounds are based on material strength/density ratios, material metallurgical stability temperature limits and coating life. The metallurgical stability temperature limit is the temperature where a notable change in the metallurgical structure or significant reduction in mechanical properties occurs. If the temperature for metallurgical stability is exceeded, it is important to consider time dependent post heating effects. Exposure to higher temperatures for significant periods of time may result in subsequent reduction in both room and elevated temperature mechanical properties and material ductility. However, test data for some materials has indicated that accumulated temperature effects of recycling from room to peak temperature have considerably less degrading effect on mechanical properties than continuous exposure for the same total time at peak temperature.

The temperature limit of 1000°F employed for titanium alloy 8Al-1Mo-1V is based primarily on the reduction in mechanical properties above this limit. Accumulative exposures to 1000°F for short periods of time will not produce subsequent reduction in room and elevated temperature mechanical properties. Continuous exposure (10 hrs.) of René 41 above 1400°F has resulted in degradation of subsequent room and elevated temperature mechanical properties; however, it is felt that short time exposures to 1600°F can be tolerated with negligible effect on mechanical properties. Ten hours of accumulative 6-minute exposures to peak temperature per flight is representative of an orbiter with a 100-flight life. The temperature limit of 2200°F utilized for thorium-dispersed, nickel chrome (TD-NiCr) is based on the metallurgical stability limit. Columbium alloy upper bound is based on coating life for 100 flights.

Booster TPS - The thermal protection arrangement for the booster is shown in Figure 3-65. Heat transfer between the shingle and tank wall is minimized by insulation and a radiation gap to limit the maximum tank wall temperature to 200°F. It is necessary to limit the maximum tank wall temperature to 200°F so that the freon blown polyurethane foam insulation and NARMCO 7343 adhesive (foam to tank) limit temperature of 200°F is not exceeded.

Methods used for attachment and support of the corrugated panels are shown in Figure 3-66. A pie shaped retainer entraps the shingles and provides a gap for thermal expansion. The arrangement allows removal of individual panels.

Pressure loads are beamed by the corrugations to supports at the forward and aft edges of the panels. The supports are attached to body frames. The attachment and support concept are similar for radiation cooled shingles of titanium, René 41 and TD-NiCr alloys with the exception a support beam, isolated from frame caps by brackets, is used to react positive pressure loads from TD-NiCr panels whereas titanium and René 41 panels are used in lower temperature zones and bear directly on frame caps through support channels. The pie shaped retainer reacts negative pressure loads on the panels. These loads are introduced into the frames through support brackets. The standoff support brackets are used to minimize the conductive heat path from shingle to primary structure.

Beaded panels are used on the shadowed surface in regions which experience low heating rates. In these areas the surface irregularities due to the beads do not significantly alter the heat inputs or aerodynamic characteristics. Panels are retained by round head screws with clamp-up bushings. Oversize holes provide for thermal expansion.

An alternate to the metallic shingle is the hardened compacted fiber (HCF) (Insulation) bonded to a fiberglass honeycomb substructure. The attachment concept is similar to that employed for the corrugated panels with the exception the panel is allowed to bear directly on the frame cap.

3.2.5 Propulsion Systems - Three major propulsion systems are required on each stage: Boost, Secondary (attitude control/orbit maneuvers) and Landing. A summary of these systems is presented in Table 3-12 for the baseline vehicle. Schematic diagrams for both the orbiter and booster propulsion systems are shown respectively in Figures 3-67 and 3-68. A more complete discussion of the baseline system requirements and design characteristics is contained in the following paragraphs.

CONCEPT "L"
MATERIAL DISTRIBUTION OF TPS SHINGLES CARRIER

NOTE: WING & VERTICAL TAIL SURFACE PANELS ARE STRUCTURAL (TITANIUM WITH RENE LEADING EDGES)

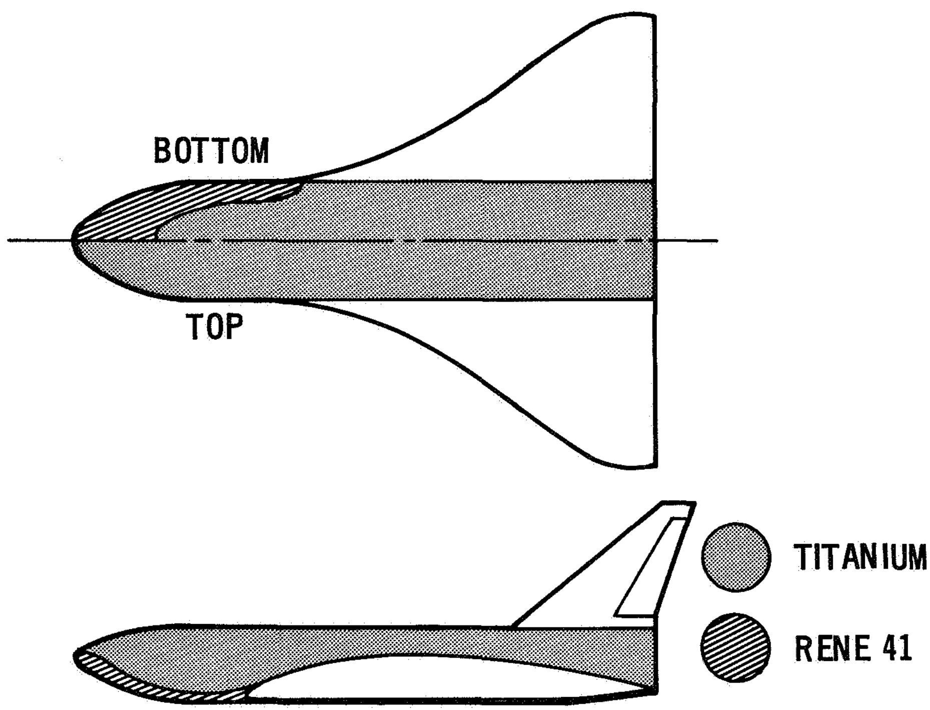


FIGURE 3-65

CONCEPT "L"

METALLIC SHINGLE TPS ARRANGEMENT

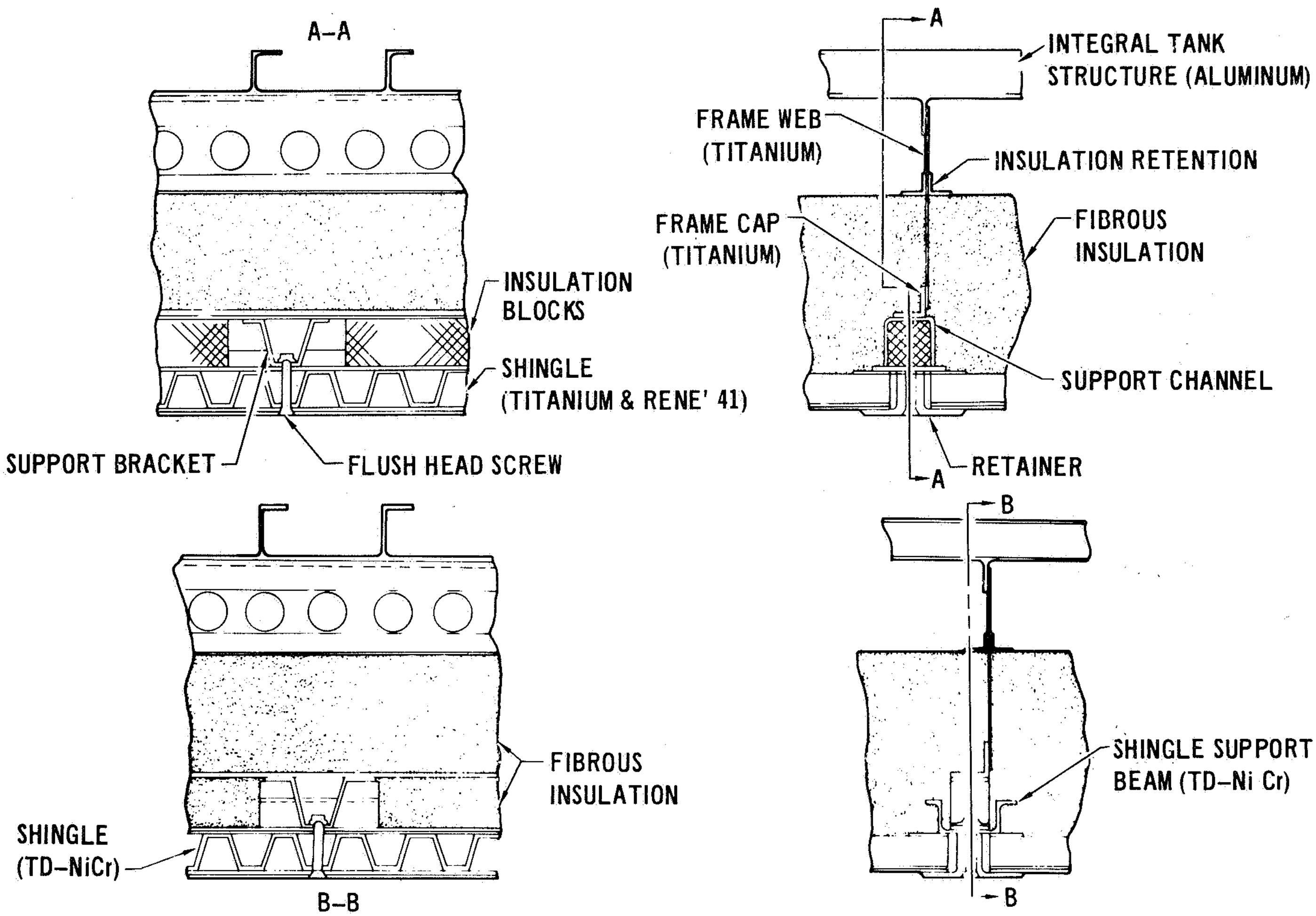


FIGURE 3-66

CONCEPT "L"

BASELINE PROPULSION SYSTEM DESCRIPTION

SYSTEM	CARRIER	ORBITER
BOOST PROPULSION	• 10 ENGINES (XLR-129); $F_{S.L.}$/ENGINES = 448,000 LB • LO_2/LH_2 PROPELLANTS; INTEGRAL TANKS • GO_2/GH_2 PRESSURIZATION	• 2 ENGINES (XLR-129); $F_{S.L.}$/ENGINE = 448,000 LB • LO_2/LH_2 PROPELLANTS; INTEGRAL TANKS • GO_2/GH_2 PRESSURIZATION
SECONDARY PROPULSION	ATTITUDE CONTROL • 12 ENGINES; F_V/ENGINE = 4,000 LB • GO_2/GH_2 PROPELLANTS • TURBOPUMP FEED	ATTITUDE CONTROL & MANEUVER • 20 ENGINES; F_V/ENGINE = 4000 LB • GO_2/GH_2 PROPELLANTS • TURBOPUMP FEED
LANDING PROPULSION	• 4 DEPLOYABLE TURBOFAN ENGINES; F_{SLS}/ENGINE = 39,000 LB (TF39) • JP FUEL	• 4 DEPLOYABLE TURBOJET ENGINES; F_{SLS}/ENGINE = 20,000 LB (JT11) • JP FUEL

TABLE 3-12

CONCEPT "L"
HL-10 PROPULSION SYSTEM

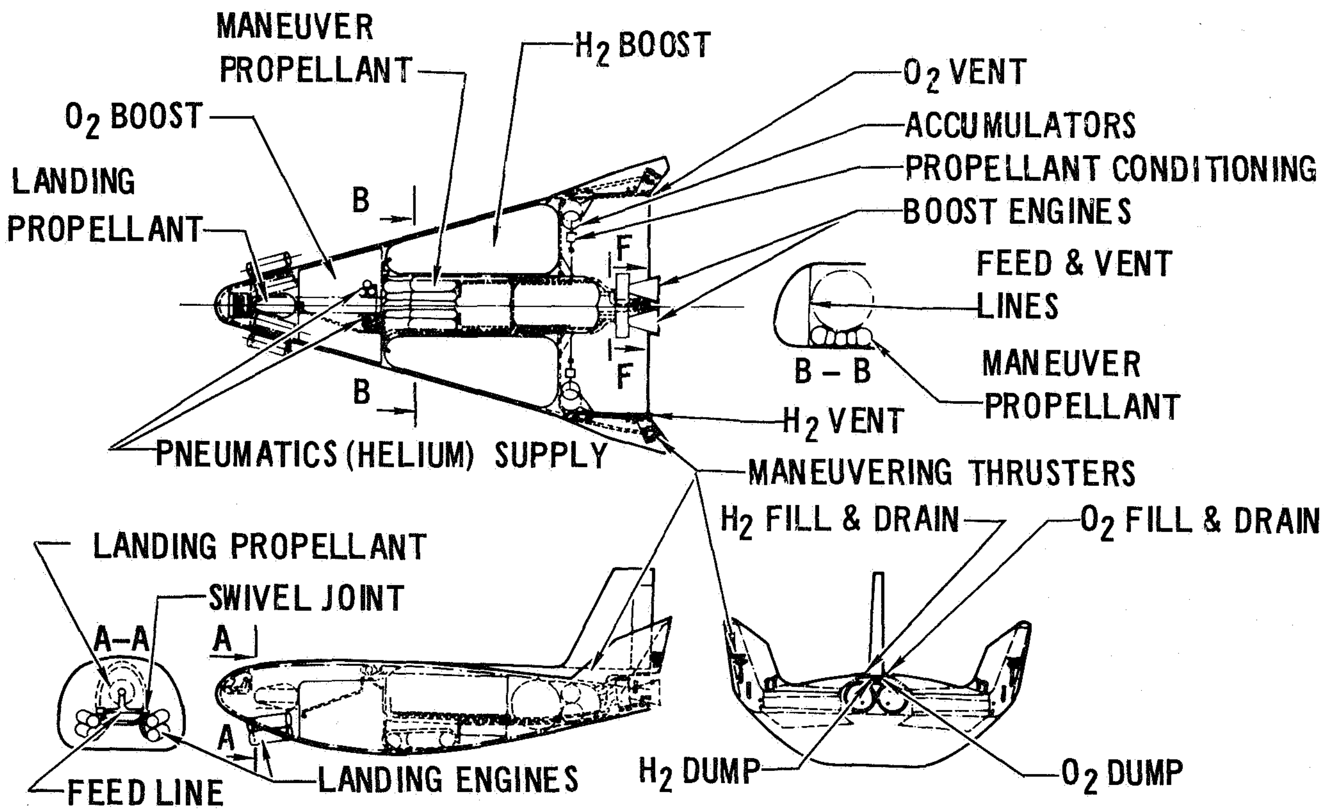


FIGURE 3-67

CONCEPT "L"
CARRIER PROPULSION SYSTEMS

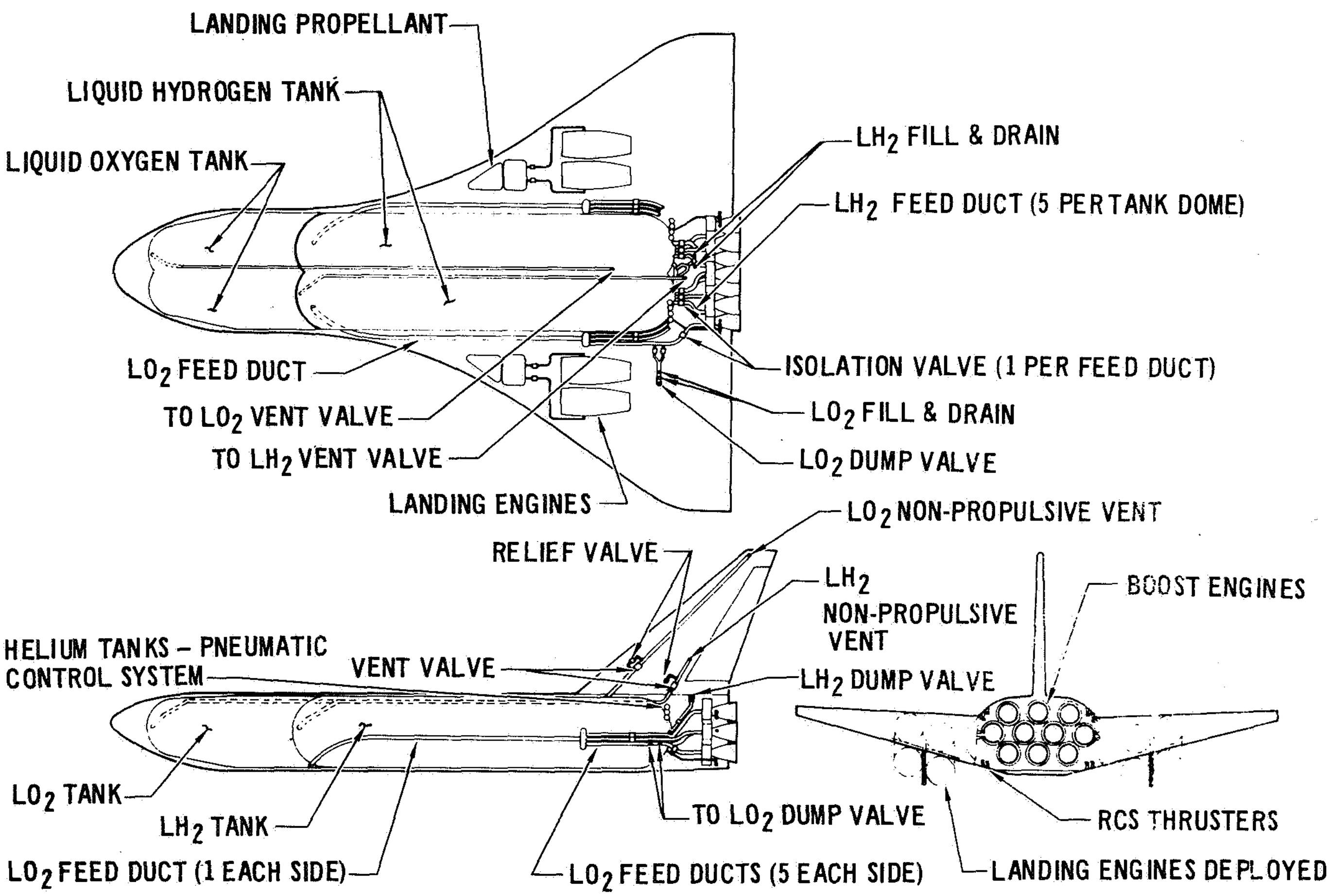


FIGURE 3-68

3.2.5.1 Boost Propulsion - The Pratt and Whitney XLR-129 engine design is incorporated in both stages; 10 in the carrier and 2 in the orbiter. The same engine is used in both stages in terms of chamber pressure, mixture ratio, sea level thrust and primary or retracted expansion ratio, resulting in the same turbomachinery and comubstion chamber designs. However, some liberty was taken with the single engine development concept in that different extended or maximum expansion ratios are used for the carrier and orbiter. Maximum utilization was made of the vehicle base areas to provide installation of maximum nozzle expansion ratios. The reduced gimbal angle and installation constraints of the orbiter allowed the installation of a nozzle expansion ratio greater than for the carrier. The corresponding increase in orbiter vacuum specific impulse is considered to produce a payload advantage that more than off-sets the increased engine development requirements.

The propellant tanks for both stages are prepressurized prior to liftoff with ground ambient helium. During flight, prepressurization is accomplished using vaporized propellants that are bled from the engines. The control systems consist of orifices and valves actuating open or closed on pressure switch command. The maximum tank pressures (relief setting) are 29 psia LOX and hydrogen on the carrier and 29 psia LOX and 33.5 psia hydrogen on the orbiter. Nominal tank pressures are 25 psia LOX and 27 psia hydrogen.

The LH_2 feed system lines on both the orbiter and carrier are 12 inches in diameter and run individually from the tankage to each engine. Two 12 inch diameter LOX lines feed the orbiter. The carrier LOX feed system consists of two lines from the tank, 16 inches in diameter, each of which branches into five, 12 inch lines, one for each engine. The hydrogen lines are externally insulated. Tank fill is through a selected feed line with the exception of the carrier LH_2 tank.

Provision is made for all propellant tankage to be vented during ground hold and flight. Both propellants are vented non-propulsively during flight. The valves sense tank pressure and open at their relief setting. A redundant relief valve design ensures tank pressure control.

The pneumatic systems for both stages are identical in design and are required for engine and stage valve actuation. Both the booster and orbiter incorporates a single 3000 psi 4.5 ft^3 ambient helium sphere with a 500 psia pressure control system to satisfy stage valve pneumatic requirements. In addition, a 1500 psia pressure control system is installed for engine supply. The orbiter uses a total of five helium spheres while the booster requires 19.

The recommended PU system is a modified closed loop system with pilot override for both stages. Propellant quantities, and thus tank mixture ratio is, determined by tank mounted instrumentation and displayed to the crew. Adjustment of the engine mixture ratio is then performed by pilot control if necessary to minimize propellant residuals. The design propellant residuals are 0.5% of loaded propellant.

3.2.5.2 Orbit Maneuvering and Attitude Control System - A secondary propulsion system is required on both the booster and orbiter to provide an attitude control and maneuver capability from the time of boost system shutdown until such time as the vehicle enters the sensible atmosphere. Major system design constraints are the study requirement to utilize O_2/H_2 propellants and the MDAC ground rule to provide the capability for mission completion in the event of a single engine failure.

The O_2/H_2 propellants are stored as liquids in low pressure tanks that incorporate screen start tanks for propellant orientation. Pressurization is accomplished using residual helium from the boost pneumatic system. The propellants are increased in pressure using turbopumps, vaporized in a high pressure heat exchanger and temporarily stored in accumulators pending demand usage by the engines. The energy source for the heat exchangers and turbopumps is the exhaust products from a GO_2/GH_2 hot gas generator tapped off the accumulators.

A group of twelve 4000 lb. thrust engines located in the base of the booster provide 3 axis attitude control. An additional pair of down firing, 4000 lb. thrust engines is located forward of the booster-orbiter attach points. These engines, in conjunction with the pitch down engines located in the booster base, provide an "upward" translation capability for stage separation.

The engines and flow components (turbopump, heat exchanger, accumulator) developed for the orbiter are also used in the booster. However, different propellant storage tanks are required because of the considerable difference in total impulse required. A single integrated system is used for both attitude control and orbit maneuver.

The propellant storage tanks incorporate a propellant orientation device (for attitude control) that consists of a start tank, screens and a refill valve. The start tank is pressurized by a cold helium system. Refill occurs during the long main orbital maneuver burns. Main tank pressurization is accomplished using vaporized propellants drawn from the accumulators. The design and operation of the turbopumps, heat exchangers and accumulators are the same as those in the booster system.

The system uses 20 engines, a group of 10 located in each outboard fin. Twelve engines provide the necessary three axis attitude control while the remaining 8 (6 aft firing, 2 forward firing) provide the required translation capability.

3.2.5.3 Landing Propulsion - The landing propulsion system provides the cruise capability necessary for return to the launch site. This is an MDAC requirement imposed to enhance the turnaround operation. The capability of level flight (thrust = drag) with an engine out is a continuation of the philosophy to design for mission completion following a single engine failure. The range requirement stems from the baseline vehicle staging velocity/altitude and includes approximately 100 NM as an allowance for the final landing maneuver and for contingency (i.e., head winds and hot day operation). The carrier vehicle L/D of 7.0 is used instead of the wind tunnel derived value of 7.3 to account for directional trim losses resulting from an asymmetrical engine out condition. Also, no benefit is taken for the lift component of thrust. The selection of JP fuel is based on minimizing development, however, an assessment of LH_2 fuel was also made. Turbofans are incorporated because of specific fuel consumption considerations.

The booster landing propulsion system utilizes four wing mounted turbofan engines that are deployed downward for operation. The required sea level static thrust of each engine is 39,000 pounds. This thrust level is almost identical to that of the TR39 engine used as the reference engine to obtain parametric cycle data. Therefore, the baseline system is considered to use existing engines of the TR39 class. The fuel system is located in the wing just forward of the engines.

An orbiter system is provided to satisfy the study requirement for a short period of powered flight during the final phase of landing. The orbiter landing propulsion system (engines and fuel) is located in the forward fuselage just aft of the crew. This is a part of the equipment arrangement effort to eliminate ballast. Four deployable turbojets are installed, each providing a sea level static thrust level of 20,000 pounds. As in the case of the booster, this thrust level is very near that of the JT11 (J58) reference engine. Thus, the orbiter system is also considered to use existing engines.

3.2.6 Weight Analysis - Concept "L" weight summaries for payload capabilities of 10,000 (15 x 17 ft) 25,000 (15 x 30 ft) and 50,000 (15 x 60 ft) lb. are presented in Tables 3-13 and 3-14. These data were based on the configuration and weight information given in Reference 2.

The weight statement of Table 3-13 is in accordance with the breakdown logic of Concept "S" as shown in Figure 3-59. A standardized format such as this enables the reader to make quick comparisons between concepts. In complying with this format some of the component weights reported in Reference 2 had to be redistributed in order to make the weight statement consistent with the other two concepts. For example, boost engine thrust structure and hydrogen tank insulation were removed from the body structure and added to the main propulsion system. In Concept "L" the attitude control and orbit maneuver system are one system where as in Concept "S" and "M" they are treated separately.

General definition of the concept in terms of its geometric characteristics, material breakdown, and component descriptions of various subsystems can be found in Table 3-14.

TABLE 3-13
CONCEPT "L" – ORBITER AND BOOSTER WEIGHT SUMMARY

SUBSYSTEM/COMPONENT (LB)	50K PAYLOAD		25K PAYLOAD		10K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
BODY STRUCTURE	(47,170)	(81,750)	(32,140)	(70,300)	(26,750)	(53,840)
INTEGRAL TANK SIDEWALLS	23,590	58,990	16,070	50,730	12,280	38,600
REMAINING BODY STRUCTURE	23,580	22,760	16,070	19,570	14,470	15,240
THERMAL PROTECTION SYSTEM	(41,300)	(27,470)	(27,970)	(22,450)	(23,460)	(18,060)
BODY	29,880	21,230	20,230	17,000	16,970	13,960
AERO SURFACES	10,430	–	7,070	–	5,930	–
BASE HEAT SHIELD	990	1,600	670	1,450	560	1,050
INSULATION FOR LANDING ASSIST ENGINES	–	4,640	–	4,000	–	3,050
AERO SURFACES	(13,510)	(104,930)	(9,150)	(90,290)	(7,670)	(69,010)
WING	–	96,960	–	83,430	–	63,760
VERTICAL TAIL	2,610	7,970	1,770	6,860	1,480	5,250
SIDE FINS	7,860	–	5,320	–	4,460	–
ELEVONS	3,040	–	2,060	–	1,730	–
LANDING GEAR	(12,770)	(24,890)	(8,360)	(20,290)	(6,540)	(15,880)
MAIN PROPULSION SYSTEM	(50,030)	(183,140)	(34,740)	(136,680)	(29,470)	(112,820)
ENGINES	13,570	66,330	9,760	47,740	8,340	40,850
GIMBALS	2,390	11,700	1,460	7,160	1,250	6,130
TANK BULKHEADS, BAFFLES & TIE RODS	15,390	41,170	10,480	35,390	8,800	27,000
TANK INSULATION	5,340	8,400	3,620	7,300	3,040	5,530
THRUST STRUCTURE	4,610	22,490	3,120	15,250	2,620	12,770
FEED SYSTEM	8,730	33,050	6,300	23,840	5,420	20,540
ORBIT MANEUVER AND ATTITUDE CONTROL SYSTEM	(4,660)	(1,220)	(3,050)	(1,120)	(2,400)	(760)
ENGINES	1,190	510	780	470	610	320
TANKS	1,285	220	840	200	660	440
ACCUMULATORS, CONDITIONING SYSTEN, PLUMBING, ETC.	2,185	490	1,430	450	1,130	300
LANDING ASSIST	(20,350)	(41,410)	(13,320)	(35,590)	(10,420)	(26,290)
ENGINES	19,570	38,410	12,810	32,480	10,020	24,420
FUEL TANKS	310	1,200	200	1,240	160	750
FEED SYSTEM	470	1,800	310	1,870	240	1,120
PRIME POWER SYSTEM	(4,557)	(3,895)	(4,557)	(3,895)	4,557)	(3,895)
BATTERIES	230	690	230	690	230	690
FUEL CELLS	400	–	400	–	400	–
REACTANT SUBSYSTEM – DRY	337	–	337	–	337	–
REACTANTS	530	–	530	–	530	–
AUXILIARY POWER UNIT	280	715	280	715	280	715
FUEL	540	575	540	575	540	575
TANK, LINES AND VALVES	80	110	80	110	80	110
INVERTERS	160	160	160	160	160	160
CIRCUITRY	2,000	1,645	2,000	1,645	2,000	1,645
HYDRAULICS	(1,240)	(1,490)	(830)	(1,250)	(680)	(980)
AERODYNAMIC CONTROLS	(2,320)	(2,550)	(1,620)	(2,180)	(1,340)	(1,760)
AVIONICS	(2,200)	(1,570)	(2,200)	(1,570)	(2,200)	(1,570)
GUIDANCE AND NAVIGATION	890	410	890	410	890	410
TELECOMMUNICATIONS	325	205	325	205	325	205
CENTRAL MANAGEMENT COMPUTER	180	180	180	180	180	180
DISPLAYS, CONTROL & SEQUENCING	480	480	480	480	480	480
FLIGHT CONTROL	75	75	75	75	75	75
CONTROL AMPLIFIERS	125	95	125	95	125	95
INSTRUMENTATION	125	125	125	125	125	125
ORDNANCE	(200)	(200)	(200)	(200)	(200)	(200)
ENVIRONMENTAL CONTROL SYSTEM	(1,940)	(430)	(1,940)	(430)	(1,940)	(430)
GAS MANAGEMENT AND PROCESSING	52	–	52	–	52	–
GAS SUPPLY AND CONTROLS	353	–	353	–	353	–
HEAT TRANSPORT	1,022	–	1,022	–	1,022	–
CREW WATER SUPPLY	11	–	11	–	11	–
HYDRAULIC SYSTEM COOLING	409	120	409	120	409	120
AIR CYCLE	–	50	–	50	–	50
COOLANT LOOP	–	215	–	215	–	215
O_2 SUPPLY	–	25	–	25	–	25
CIRCUITRY, LINES, FITTINGS	93	20	93	20	93	20
CREW AND FURNISHINGS	(600)	(600)	(600)	(600)	(600)	(600)
CREW	400	400	400	400	400	400
FURNISHINGS	200	200	200	200	200	200
BALLAST	0	0	0	0	0	0
CONTINGENCY	(20,228)	(47,940)	(13,988)	(39,060)	(11,778)	(30,825)
MAIN PROPELLANT	(928,280)	(2,729,960)	(538,400)	(2,181,840)	(453,710)	(1,455,110)
USABLE – BOOST	868,570	2,702,660	499,980	2,160,060	423,310	1,440,570
ON-ORBIT MANEUVER ($\Delta V = 2{,}000$ FPS)	49,540	–	32,450	–	25,400	–
RESIDUAL AND PRESSURANT	10,170	27,300	5,970	21,780	5,000	14,540
JET FUEL	(15,520)	(59,950)	(10,170)	(62,160)	(7,960)	(37,280)
USABLE	15,220	58,770	9,970	60,940	7,800	36,550
RESIDUAL	300	1,180	200	1,220	160	730
ACS PROPELLANT	(3,040)	(1,210)	(1,990)	(930)	(1,560)	(800)
USABLE	2,950	1,180	1,930	900	1,510	780
RESIDUAL AND PRESSURANT	90	30	60	30	50	20
PAYLOAD	(50,000)	–	(25,000)	–	(10,000)	–
STAGE LIFT-OFF WEIGHT	1,219,915	3,314,605	730,225	2,670,835	603,235	1,830,110
GROSS LAUNCH WEIGHT	4,534,520		3,401,060		2,433,345	

TABLE 3-14

CONCEPT "L" – GEOMETRICAL, MATERIAL AND SYSTEM DESCRIPTION DATA

	50 K PAYLOAD		25 K PAYLOAD		10 K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
LENGTH – FT	130	210	107	195	98	170
PAYLOAD CYLINDER DIMENSIONS – FT	15 DIA X 60	-	15 DIA X 30	-	15 DIA X 17	-
AREAS – SQ FT						
BODY WETTED AREA – OML	14,800	21,946	10,044	18,912	8,470	14,374
EMPENNAGE WETTED AREA						
VERTICAL TAIL (1)	1,170	3,110	792	2,680	664	2,040
SIDE FINS (2)	2,322	–	1,574	–	1,320	-
ELEVONS (2)	1,356	-	919	–	771	–
WING WETTED AREA	–	16,610	–	14,370	–	10,900
DOOR AREA						
VOLUME – CU FT						
BODY – OML	101,721	186,836	56,719	149,116	43,577	99,647
WING		56,171	–	44,831	-	29,958
BODY STRUCTURE – WEIGHT (LB)						
ALUMINUM	47,170	81,750	32,146	70,300	26,750	53,840
TPS – WEIGHT (LB)/WETTED AREA (SQ FT)						
BODY						
COLUMBIUM	990/400	1,600/696	670/271	1,450/600	560/227	1,050/456
RENE 41	14,530/7,850	2,310/1,450	9,840/5,313	1,850/1,248	8,760/4,455	1,570/948
TD-NICKEL	12,390/3,720	–	8370/2536	–	7,020/2123	-
TITANIUM	2,990/2,830	18,920/19,800	2,020/1,924	15,150/17,064	1,690/1,615	12,440/12,970
WING – MICROQUARTZ	–	4,640/ –	–	4,000 –	–	3,050 –
VERTICAL FIN						
RENE	2,380/1,170	-	1,610/792	–	1,350/664	-
TD-NICKEL (LEADING EDGE)	300/ –	–	200/ –	–	170/ –	–
SIDE FINS						
TD-NICKEL	3,260/1,435	–	2,210/973	–	1,850/815	–
RENE	1,400/887	-	950/601	-	800/505	-
ELEVONS						
RENE	1,530/670	–	1,040/454	–	870/381	-
TD-NICKEL	1,560/686	-	1,060/465	–	890/390	-
AERO SURFACES – WEIGHT (LB)						
WING						
RENE	–	11,070	-	9,510		7,280
TITANIUM	–	85,890	–	73,920	-	56,480
VERTICAL FIN						
RENE	–	1,560	–	1,340	–	1,030
TITANIUM	2,610	6,410	1,770	5,520	1,480	4,270
SIDE FIN						
TITANIUM	7,870	–	5,320	–	4,460	-
ELEVONS						
TITANIUM	3,040	–	2,060	-	1,730	–
MAIN PROPULSION						
TANK BULKHEADS, BAFFLES AND TIE RODS						
ALUMINUM – WEIGHT (LB)	15,390	41,170	10,480	35,390	8,800	27,000
TANK INSULATION						
POLYNETHANE FOAM-WT (LB)/AREA (SQ FT)	5,340/12,450	8,400/17,190	3,620/8,428	7,300/14,790	3,040/7,060	5,530/11,260
THRUST STRUCTURE						
TITANIUM – WEIGHT (LB)	4,610	22,490	3,120	15,250	2,620	12,770
ENGINE DESCRIPTION						
TYPE	HI PC BELL	HIGH PC BELL	HIGH PC BELL	HIGH PC BELL	HIGH PC BELL	HIGH PC BELL
NUMBER	2	10	2	10	2	10
THRUST PER ENGINE-LBS (VAC)	768,000	749,700	520,600	508,200	436,000	425,600
PROPELLANT TYPE	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
ORBIT MANEUVER AND ATTITUDE CONTROL SYSTEM						
TANKS – LOX AND LH_2						
ALUMINUM – WEIGHT (LB)	1,285	220	840	200	660	140
VOLUME – CU FT	2,460	56	1,610	43	1,260	37
ENGINE DESCRIPTION						
TYPE						
NUMBER	20	12	20	12	20	12
THRUST PER ENGINE – LB (VAC)	7,420	4,450	4,000	4,000	2,860	2,660
PROPELLANT TYPE	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2	GO_2/GH_2
LANDING ASSIST						
TANK – BLADDER TYPE						
VOLUME – CU FT	330	1,283	218	1,330	170	800
ENGINE DESCRIPTION						
TYPE	TURBO JET	TURBO FAN	TURBO JET	TURBO FAN	TURBO JET	TURBO FAN
NUMBER	4	4	4	4	4	4
THRUST PER ENGINE – LB (SLS)	30,500	46,600	20,000	39,000	15,600	29,800
FUEL TYPE	JP-4	JP-4	JP-4	JP-4	JP-4	JP-4
PRIME POWER SYSTEM						
BATTERIES (AgO–Zn)						
ENERGY PER BATTERY – KWH	6	6	6	6	6	6
NUMBER	2	6	2	6	2	6
FUEL CELL						
POWER OUTPUT PER FUEL CELL – KW	2.0–2.5	–	2.0–2.5	–	2.0–2.5	-
NUMBER	4	-	4	–	4	–
AUXILIARY POWER UNIT						
NUMBER	3	8	3	8	3	8
ENVIRONMENTAL CONTROL SYSTEM						
NUMBER OF CREW	2	2	2	2	2	2
MISSION DURATION – DAYS	7	2	7	2	7	2

3.3 Analysis of Concept "M" - The analysis of Concept "M" consisted of defining a set of ground rules and assumptions, providing detail descriptions of the major subsystems and the generation of a detailed weight statement. Discussions relative to each of these items is contained in this section of the report. It should be noted that the 12,500 pound payload configuration is highly optimistic. This configuration was generated early in the NASA-MSC study and is not considered entirely consistent since the ground rules for this payload case were different than the baseline 25,000 pound case.

3.3.1 Ground Rules and Assumptions - The general ground rules and assumptions applied to the analysis of Concept "M" are listed below. Additional specific information relative to the core vehicles used in this concept can be obtained from Reference 3.

- Orbiter and booster stages same as those baseline configurations defined in NASA-MSC study under Contract NAS9-9204 Schedule II.
- Payload Considerations
  - 45,000 lb in a 15 ft dia., 60 ft long envelope
  - 25,000 lb in a 15 ft dia., 60 ft long envelope
  - 12,500 lb in a 9 ft dia., 34 ft long envelope
- High chamber pressure bell nozzles used for main propulsion system on both core vehicles
- Boost engines are the same size for both core stages for any one configuration
- Boost propellants are LOX/LH_2
- Series burn with no propellant transfer between core stages
- On-orbit ΔV capability equal to 2000 fps
- Orbit maneuver and attitude control system propellant - LOX/LH_2
- Landing assist engine - turbofan for both stages
- Nominal orbit altitude of 270 nautical miles and an inclination of 55°
- Insertion orbit of 51 x 100 nautical miles
- Mission duration - 7 days
- Both stages have a 2 man crew
- Crew will operate in a shirtsleeve environment
- Thermo-structural system designed to a 3 g normal load factor and a 1700°F temperature limit
- Orbiter entry angle of attack equal to 60°
- Prime power for orbiter and booster is supplied respectively by H_2-O_2 matrix type fuel cells and rechargeable AgO-2N batteries
- Three completely independent hydraulic subsystems

3.3.2 Concept Description

3.3.2.1 Orbiter - The orbiter is a fixed wing reusable vehicle accommodating a crew of two with a payload capability of 25,000 pounds to and from orbit. The payload cargo bay is 15 ft in diameter and 60 ft long and payload deployment capability is provided. The orbiter controls for the subsonic landing and approach consists of conventional ailerons, elevators, rudder and double slotted flaps. The RCS system provides orientation control throughout entry and orbital phases. Four (4) turbofan engines provide power for conventional airplane flying qualities and landing practices. A retractable tricycle landing gear is provided. Two (2) boost engines are provided for initial orbital injection, orbital maneuvering and deorbit.

The arrangement of key features are shown in Figure 3-69. The turbofan cruise engines are located in the nose of the vehicle to provide a favorable center of gravity for subsonic, horizontal flight. The on-orbit propellant is located as close to the rocket engines as possible to minimize trapped fluid and line losses. The forward interstage attach point is located at the orbiter gross weight center of gravity so that the stage separation is mainly translational with a minimum of rotation for the orbiter.

The electrical power equipment, batteries and fuel cells are located in the forward section to aid in locating the center of gravity as far forward as possible.

The payload actuation mechanism is located in an unpressurized area. This mechanism can be used to rotate the payload and extend it out over the front of the vehicle when docking is required for the mission.

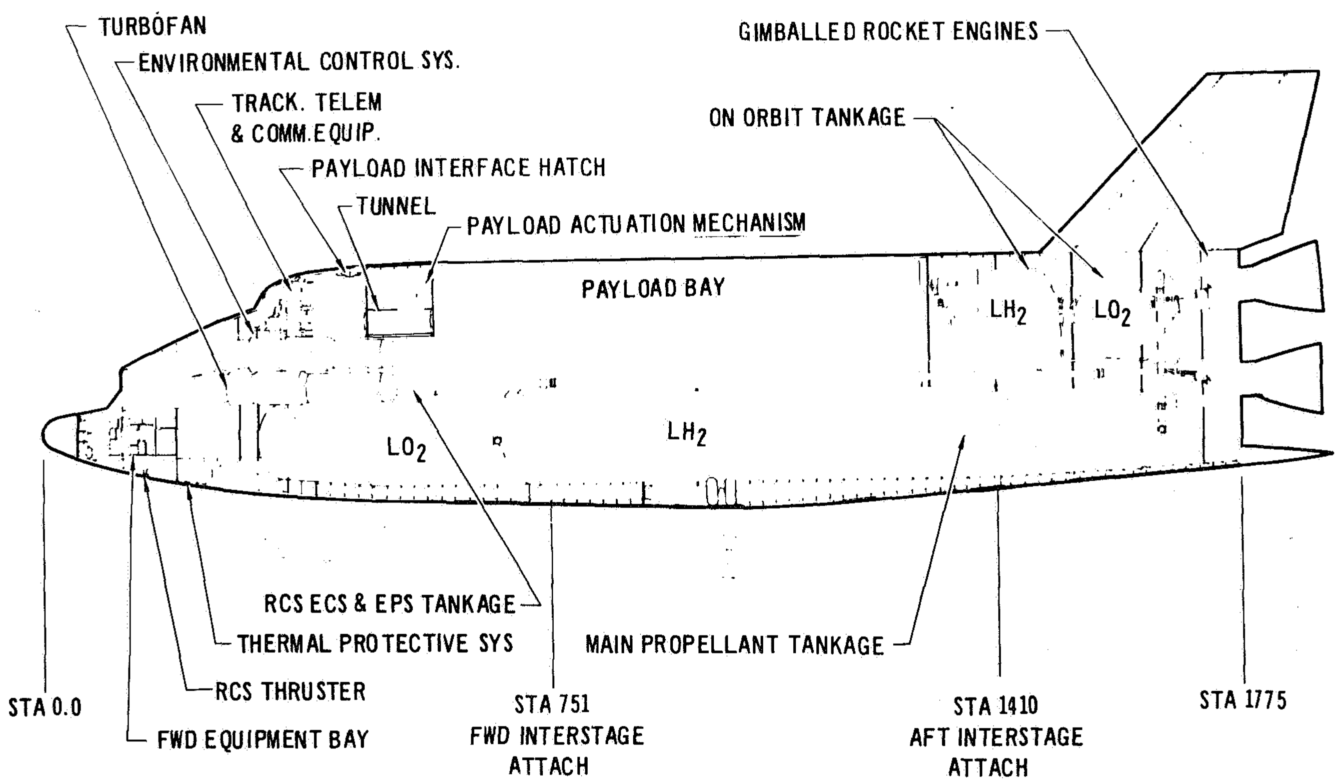
The equipment located in the pressurized area aft of the crew is normally used by the crew during the mission.

The figure shows the design approach for subsystem integration with emphasis given to location of equipment in a forward equipment bay, installation of environmental control system adjacent to cabin, provision of guidance and navigation system on a "common base" to expedite alignment and checkout, and proximity of in-flight equipment for rapid crew access and control. This approach enhances reliability, alleviates maintenance problems, and provides c.g. control.

Also shown is the ingress/egress features for the two man flight crew. IVA crew transfer is possible by two (2) routes: either through the payload tunnel, or through the payload interface hatch. EVA can be accomplished through the

CONCEPT "M"

INBOARD PROFILE – ORBITER



payload interface hatch. Ingress/egress after launch mating will be done via the payload interface hatch while post landing and ferry operation ingress/egress is realized through the lower hatch and nose gear area.

3.3.2.2 Booster - The booster, shown in Figure 3-70, is powered during ascent by ten (10) bell nozzle 400,000 lbs. thrust rocket engines using LO_2 and LH_2 propellants. Six (6) turbofan cruise engines, installed well forward to aid in c.g. control are provided for flying back to the launch site giving an all azimuth launch capability. The structural design of the booster is similar to the orbiter but somewhat simpler because no payload bay discontinuity is present.

The thermal protection consists of only hardened compacted fibers over the high temperature regions of the fuselage and aerodynamic surfaces.

3.3.3 Structural Design - Orbiter/Booster structures are described in this section. Weight optimization was primary in design conception and choice of materials. Criteria and design loads generated were coordinated with the NASA-MSC Shuttle group. The basic design philosophy included the following: Fiscal year 1972, "State-of-the-Art" technology, the employment of conventional design concepts, and the utilization of elements of structure in multiple functions.

3.3.3.1 Orbiter Structure - Primary structures are shown in Figures 3-71 and 3-72. Basic body bending/shear structure is made up of upper longerons adjacent to the payload compartment and the propellant tank structures below the payload joined by fuselage side skin panels. Two integrally stiffened cylindrical tank shells are joined at a common keel web in a "double bubble" arrangement. Side panels are single skin, stiffened by corrugations. These panels and payload doors are the upper surface of the fuselage. Tank shell structure is aluminum for compatibility with propellants and protected by moldline Thermal Protection System (TPS) shingles. Shell stiffening frames spaced at 20 inch intervals also support the TPS, upper side panels and longerons. Frames are titanium to minimize heat conductance to the tanks. The upper structures are warm during launch and entry, and also are titanium for good strength/weight ratio at elevated temperatures.

The forward fuselage structural shell is titanium single skin stiffened by corrugations and frames, and forms the M.L. except where non-structural surfaces exist, such as engine and nose landing gear doors. Intercostals and frames are transition structures between the forward fuselage and the propellant tank.

Surface TPS is radiation cooled. Insulation (silica HCF) is bonded directly to the forward fuselage shell surface aft to the propellant tanks. In the main

CONCEPT "M"
IN-BOARD PROFILE - BOOSTER

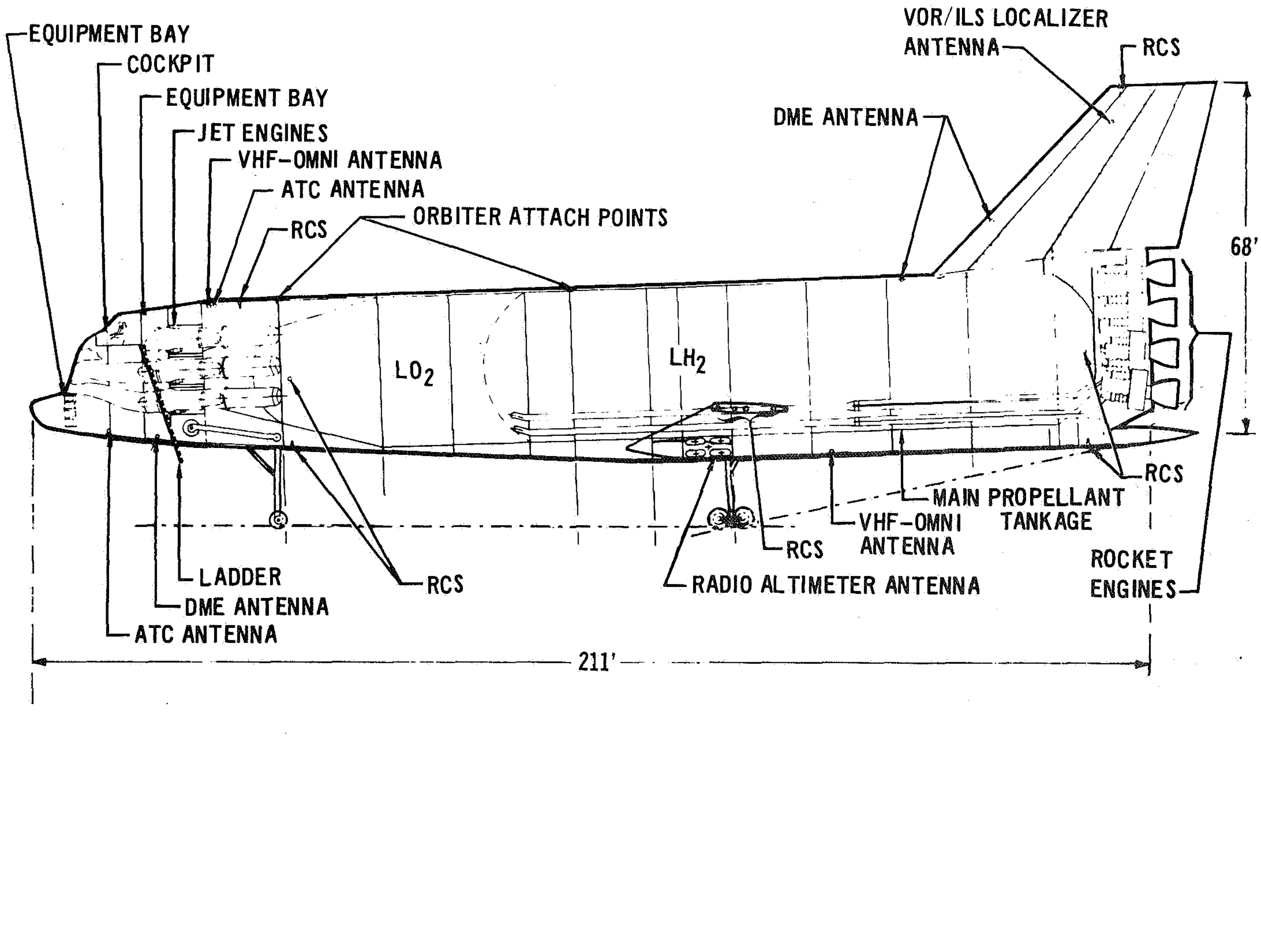


FIGURE 3-70

CONCEPT "M"
STRUCTURAL ARRANGEMENT - ORBITER

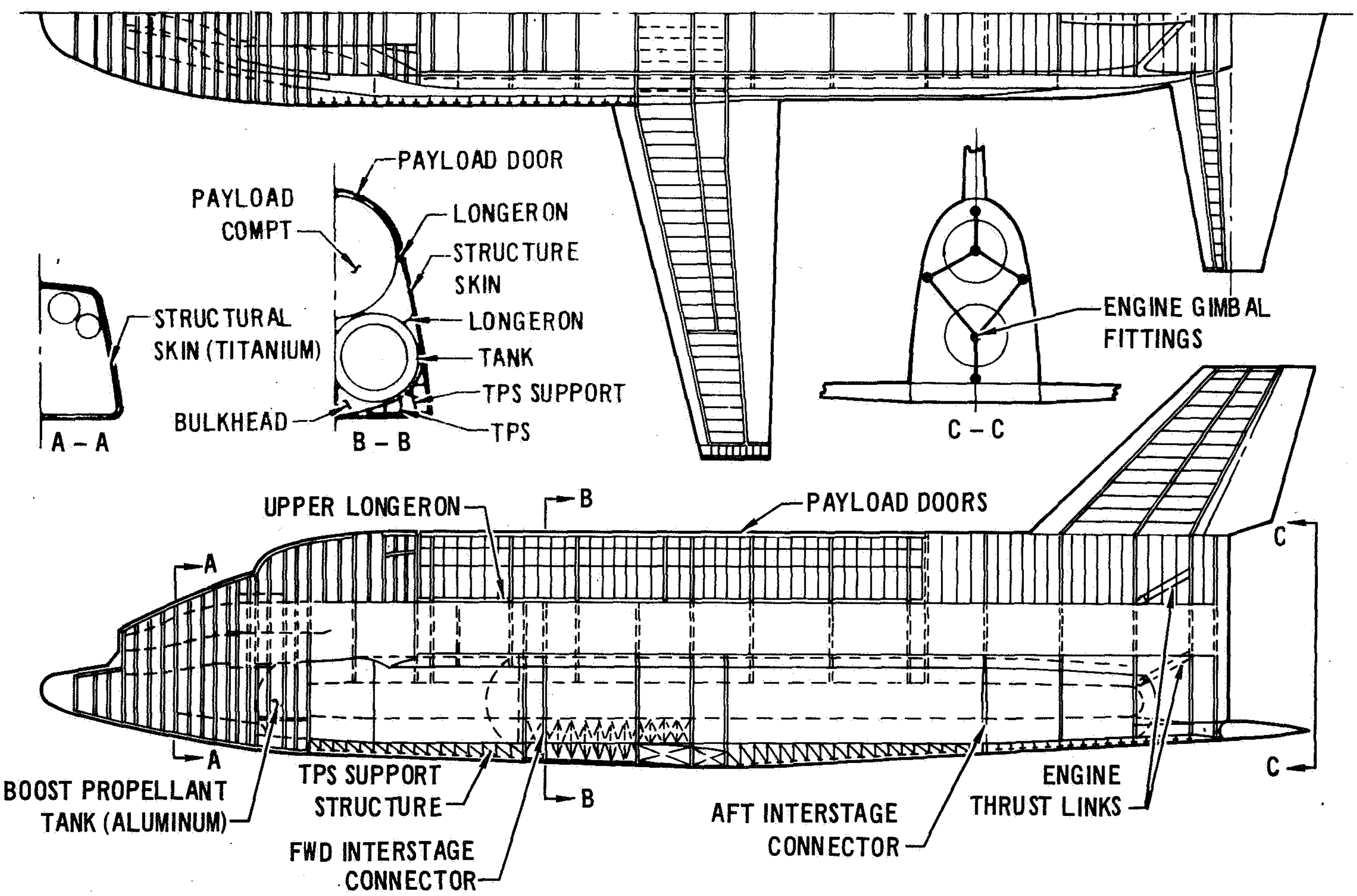


FIGURE 3-71

CONCEPT "M"
PRIMARY STRUCTURE - ORBITER

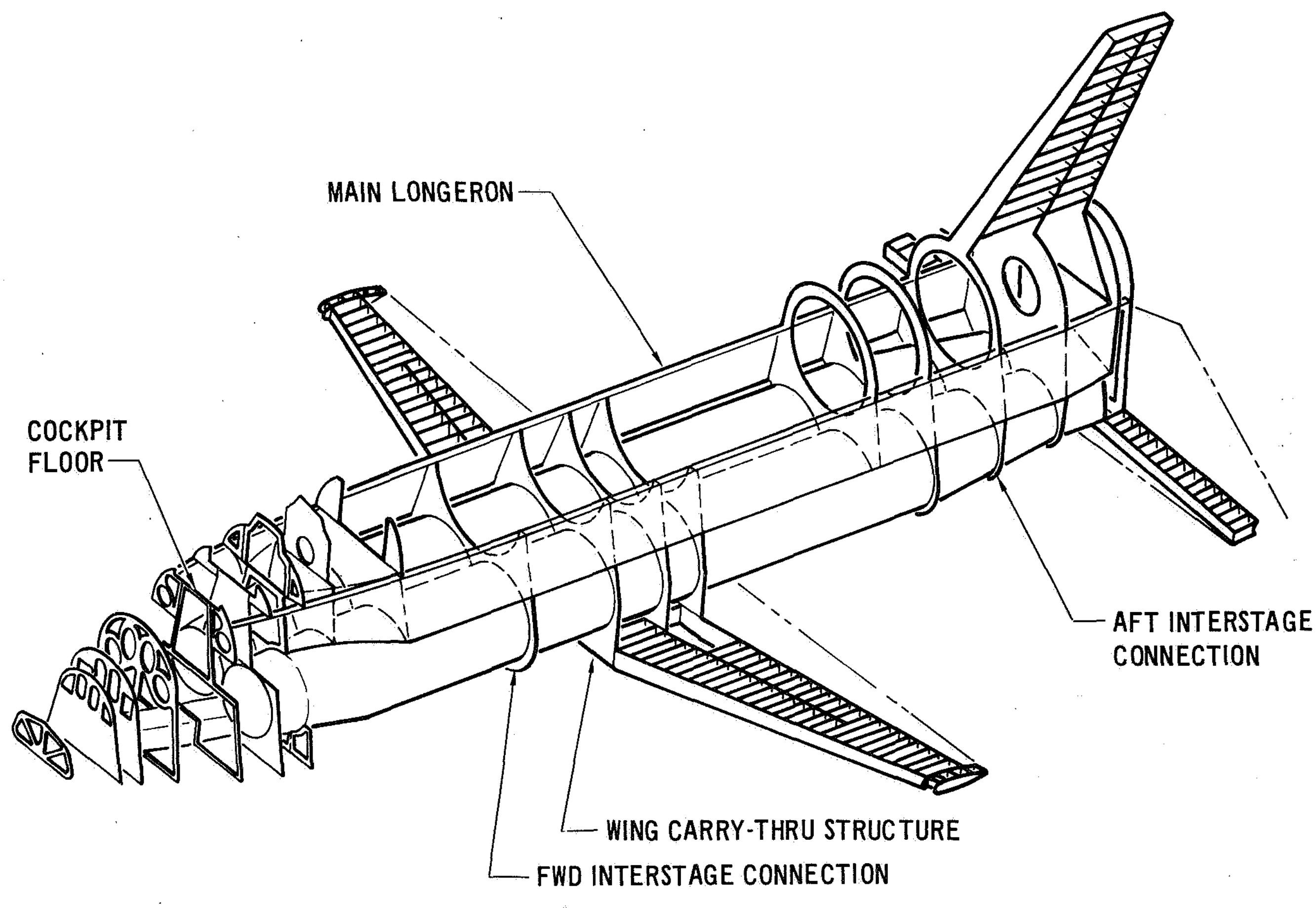


FIGURE 3-72

body area twenty inch long HCF shingle panels form the bottom and the sides up to approximately six feet above the chine lines. Single thickness beaded titanium panels form the surface between the HCF shingles and fuselage structural side skins. HCF is bonded to fiberglass honeycomb panels which distribute surface pressure loads to small lateral shingle support beams. The beams are attached to the tank shell stiffening frames by titanium links spaced at approximately 24 inches across the fuselage. Removable Pi shaped elements attached to the beams retain the shingles and provide a gap for thermal expansion.

Boost engines are supported by a tripod arrangement of linkage thrust structures for each engine. Linkage loads are transferred to the keel web, upper longerons and frames at stations 1635 and 1717. The frames also serve as main support elements for vertical and horizontal tails.

Jet engines are supported on longitudinal intercostals attached to the forward fuselage shell and by bulkheads at stations 320, 362, and 400. The bulkheads also serve as primary structures supporting cabin pressurization and nose gear loads.

The wing is attached to the fuselage at three major frames in the plane of wing spars at stations 391, 972, and 1024, and to the keel web in the plane of the wing C_L rib. Normal wing loads and symmetrical wing torque are supported at the frames and drag loads are supported at the keel web.

3.3.3.2 <u>Booster Structure</u> - The booster fuselage as shown in Figure 3-73 is similar in concept to the orbiter fuselage. The main propellant tanks are "integral" aluminum body structure and carry overall vehicle loads as well as internal pressures. The forward fuselage primary structure is the outer shell which consists of stiffened titanium skins and frames, protected from ascent and reentry heating with external HCF similar to the arrangement on the orbiter forward fuselage.

Transfer of overall body loads from the outer shell of the forward fuselage to the main propellant tanks utilizes intercostals and frames at stations 566 and 790. Propellant tanks become the primary structure from this point aft to the thrust and tie-down structures. The thermal protection system, similar to that of the orbiter consists of shingles supported on beams and links to stiffening rings on the primary body structure.

The booster thrust structure is a conical shell extension of the aft end of the H_2 tank. Seven of the ten engines mount on intercostals attached to the conical shell and two major rings. Three engines intercostals attached to the conical shell and two major rings. Three engines central to the shell are mounted on beams which attach to the shell. The vehicle is supported on the pad in launch

CONCEPT "M"
STRUCTURAL ARRANGEMENT-BOOSTER

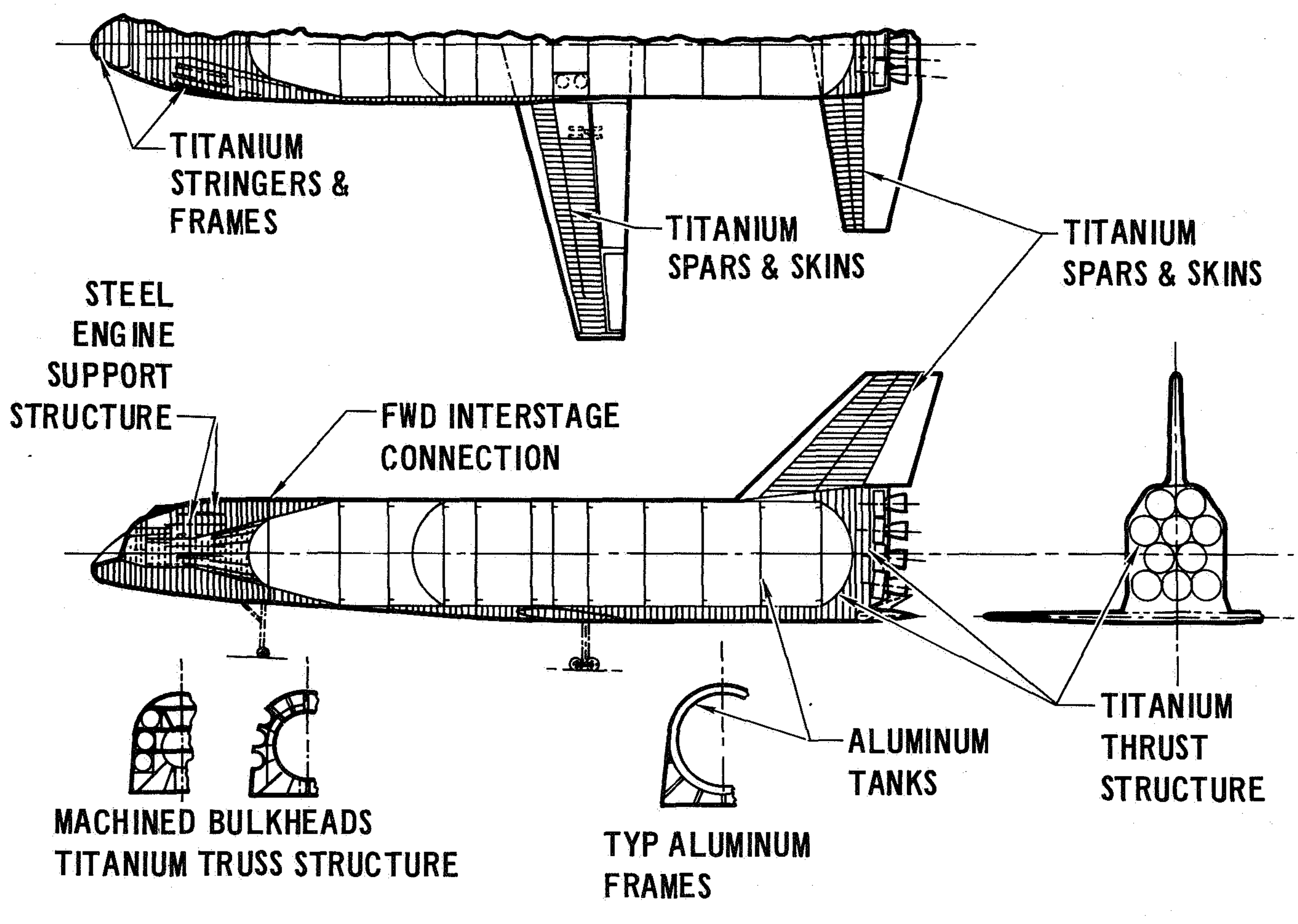


FIGURE 3-73

attitude at six hard points in the thrust cone structure. The hard point loads are transmitted to the thrust cone structure by intercostals arranged in a manner similar to the engine mounting intercostals.

Major rings in the thrust cone also distribute vertical and horizontal tail loads to the body structure (thrust cone).

The concept of surface TPS is similar to that for the orbiter except that shingles cover the entire main body area for tank protection. Temperatures are lower than for the orbiter such that HCF shingles are limited to the bottom and side regions within approximately four feet of the chine lines. The remaining areas are covered by the lightweight single thickness beaded titanium panels over the sides and top and a smooth titanium single skin, stiffened by internal corrugations on the bottom center of the fuselage.

3.3.3.3 Wing Structures - The orbiter, as shown in Figure 3-74, and booster wings are similar in concept.

The primary two cell wing box is made of 6Al-4V titanium with integrally stiffened skins of conventional arrangement. The main box is protected from reentry heating by external insulation (HCF) bonded to the lower surface. The thickness of the HCF is established to not exceed a bond line temperature of 500°F. The upper wing surface experiences temperatures of less than 800°F, and therefore is not insulated. The orbiter wing leading edge (L.E.) is constructed of carbon/carbon composite honeycomb sandwich material that serves as structure and requires no additional TPS. The titanium structural box is insulated from L.E. radiative heat by a layer of HCF on the front spar. The Booster wing leading edge experiences lower temperatures, relatively, and is a titanium structure with external insulation (HCF).

3.3.4 Thermal Protection System - Heat protection may be concentrated on the lower fuselage surfaces for vehicles entering at high angles of attack. The baseline entry angle of attack is 60°. There are several advantages for this entry attitude. The heating time is extremely brief, therefore, the total heat is relatively small and the resulting TPS weight is reduced. Severe heating is experienced only on the bottom of the vehicle. The vehicle sides and tops are cool enough so that titanium metal may be used with a minimum of TPS weight. At this high angle of attack for lightly loaded (low $\frac{W}{S}$) vehicles, very little

CONCEPT "M"

WING STRUCTURAL ARRANGEMENT – ORBITER

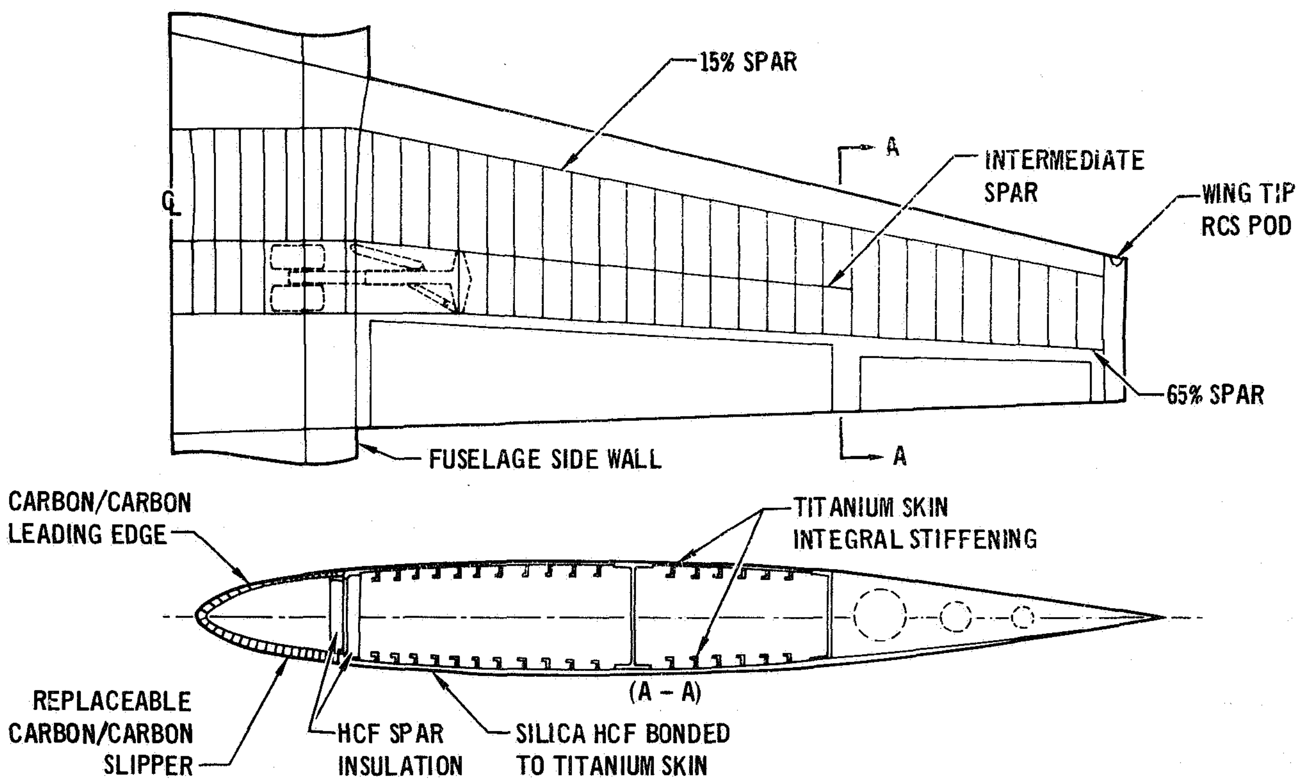


FIGURE 3-74

turbulent heating is expected on the lower fuselage surface. All of these advantages reduce the thermal protection weight. The disadvantage of a high angle of attack is that the lateral (or cross) range is quite restricted.

3.3.4.1 Orbiter TPS - A description of the orbiter TPS for entry at 60° is illustrated in Figure 3-75. Pyrolized carbon laminate is used on the nose cap and wing leading edge regions where temperatures exceed 2500°F. The majority of the upper fuselage surface, upper tail, and upper wing areas are protected with titanium skin because the temperatures are below 800°F. Hardened compacted fiber (HCF) insulation made of silica and bonded to honeycomb sandwich panels is used to protect the lower fuselage area. On the lower wing and tail areas, and on the forward regions of the fuselage, HCF is bonded directly to the titanium skin. Where HCF is bonded directly to titanium, the metal skin is structural, and is not considered part of the TPS weight.

A detail of the TPS on the bottom of the fuselage and the lower side regions of the fuselage is indicated in Figure 3-76. A silica HCF material is used with a 15 pcf density. This HCF has a silica cloth facing that is used to provide increased resistance to rain erosion and servicing damage. This facing has a high emittance coating of cobalt oxide. The outer layer of HCF is bonded with a film adhesive to a fiberglass honeycomb sandwich. Adhesive temperatures are limited to 500°F in this design to obtain the maximum reuse capability. The honeycomb sandwich panels are attached to the cryogenic tank rings with titanium structural links. These titanium links are designed to minimize the heat short between the exterior panel and the cryogenic tank rings. A low density fibrous insulation blanket of TG 15000 is supported across the tops of the cryogenic tank rings to form a relaunch purge space between the tank wall and the insulation blanket. Holes in the tank rings permit the purge gas flow to pass from one ring section to the next. On the inside of the hydrogen tank a polyurethane foam is bonded to the tank wall.

The cryogenic foam and the purge flow space are better illustrated in Figure 3-77. The soft insulation blanket (TG 15000) forms the outer wall for the purge base; the cryogenic tank forms the inner wall for the purge space. A uniform purge space has several advantages. It prevents locally starved regions of purge gas (using dry nitrogen) from becoming so cold that the purge gas itself turns to a liquid or frost. Use of a uniform purge space also permits thinner cryogenic foam for a specific lower limit on purge gas temperature. The insulation

CONCEPT "M"
BASELINE TPS DESCRIPTION
(α=60°Entry Trajectory)

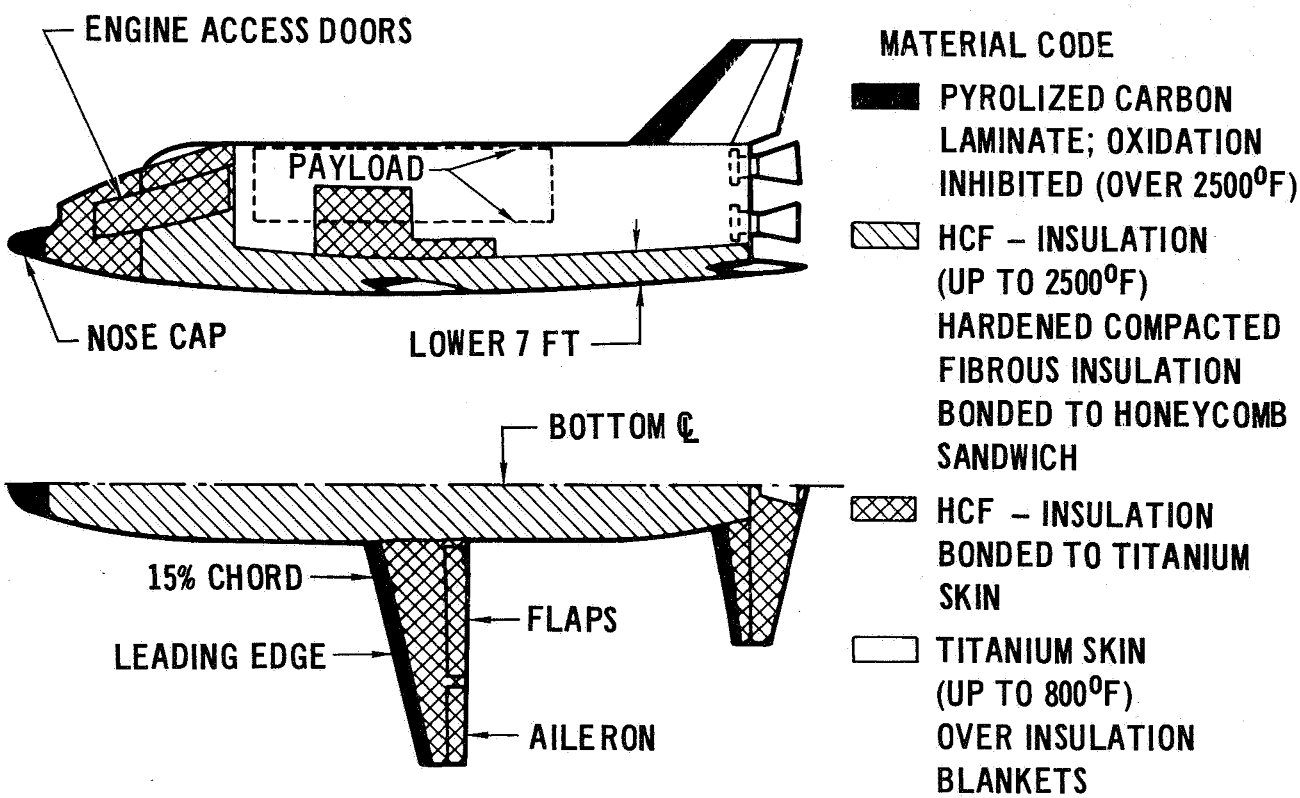


FIGURE 3-75

CONCEPT "M"
TPS DETAIL – LOWER FUSELAGE

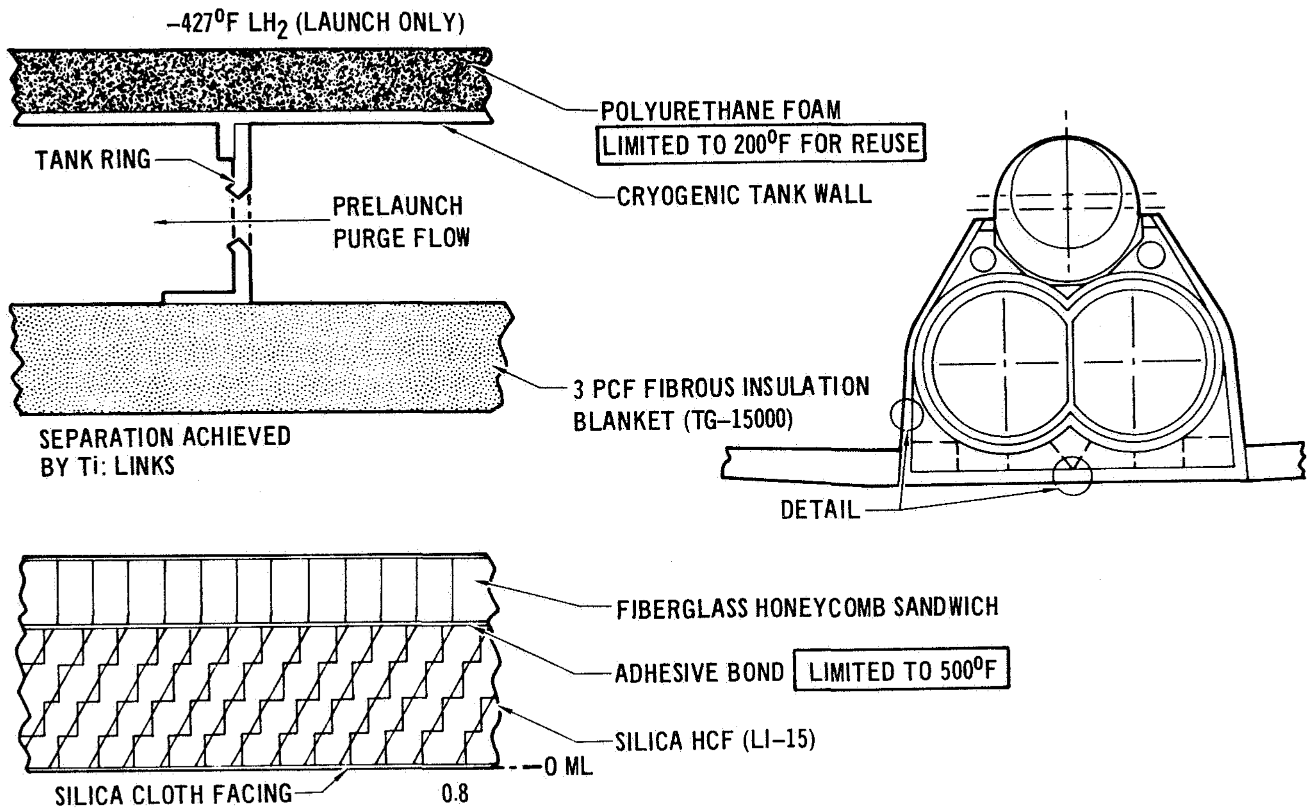
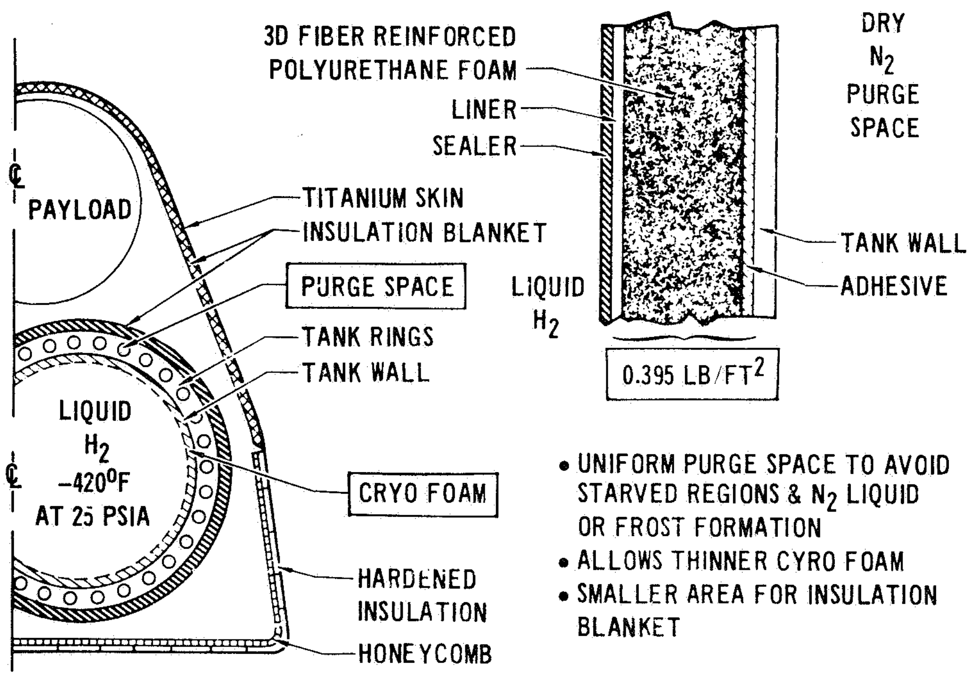


FIGURE 3-76

CONCEPT "M"

TPS DETAIL – CROSS SECTION
(Purge Space and Cryo Foam)



- UNIFORM PURGE SPACE TO AVOID STARVED REGIONS & N_2 LIQUID OR FROST FORMATION
- ALLOWS THINNER CYRO FOAM
- SMALLER AREA FOR INSULATION BLANKET

FIGURE 3-77

blanket wrapped around the cryogenic tank is smaller in area than if the blanket were supported near the outer moldline. The details of the foam used inside the liquid hydrogen tank are illustrated on the right of Figure 3-77. A 3-D fiber reinforced polyurethane foam is bonded to the inside of the hydrogen tank wall. The foam is covered with a scrim cloth liner and two wipe coats of sealer. This insulation is basically the same concept currently used on the Saturn SIV-B launch vehicles. The insulation design allows hydrogen gas to permeate into the foam but prevents liquid hydrogen from entering the insulation and causing a heat leak. A half inch of this insulation is considered adequate and has a unit weight of 0.395 lbs per sq ft.

The approach selected for areas where the temperatures exceed 2500°F as on wing leading edge is a replaceable carbon slipper concept. Inhibited carbon will oxidize where the temperatures exceed 2500°F. After several entry flights this oxidation may change the aerodynamic characteristics of the wing which are important for subsonic cruise flight. The replaceable slipper leading edge construction permits a relatively inexpensive part to be designed that can be replaced when necessary. Behind the inhibited carbon slipper is a carbon/carbon honeycomb structure in the leading edge that is good for 100 flights provided the surface of the carbon/carbon never exceeds 2500°F. The slipper consists of a carbon/carbon external surface approximately 3/10 of an inch thick that is backed by zirconia insulation and attached at local spots to the honeycomb sandwich. These attachment points are insulated with zirconia plugs. The slipper is considered only in those areas where temperatures above 2500°F are expected.

3.3.4.2 Booster TPS - Two versions of a thermal protection system are illustrated for the booster. Figure 3-78 illustrates the baseline TPS. The majority of the area is below 800°F and is protected by titanium skin over insulation blankets. Those areas on the lower wing, horizontal tail, and the forward areas of the fuselage that exceeds 800°F are protected by the hardened compacted fiber insulation. The total TPS weight for the booster is estimated at 30,130 lbs. This weight includes titanium shingles, HCF, insulation blankets, cyrogenic foam inside the hydrogen tank, and base heat protection. (Where HCF is bonded directly to titanium that serves as structural skin the titanium is not included in the TPS weight.) An alternate TPS for the booster considers the use of all metals. The majority of the area is titanium. Those areas above 800° are protected by Rene except for the nose cap and the wing leading edges where the temperature exceeds 1600°F, and the columbium is used.

CONCEPT "M"
BOOSTER TPS DESCRIPTION
51 n.m. Insertion
α =60°Entry

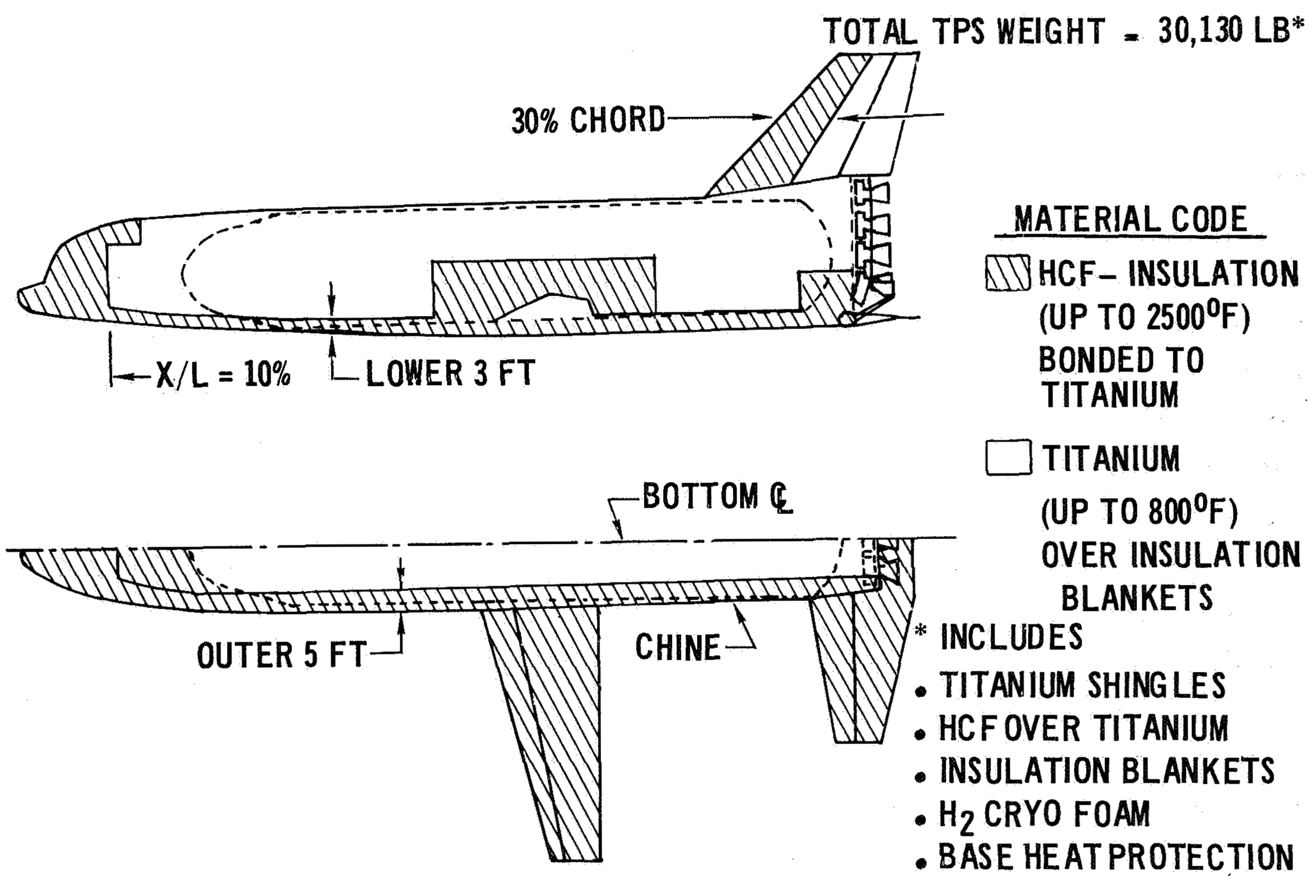


FIGURE 3-78

3.3.5 Propulsion Systems - The propulsion systems required on the booster and orbiter mission include: (1) a boost propulsion, (2) attitude control, and (3) cruise propulsion for both the booster and orbiter; and an orbit maneuvering system for the orbiter.

3.3.5.1 Boost Propulsion - The boost engines were sized accounting for the ΔV losses during boost, engine out capability, base area contribution to performance, and commonality of engines between the booster and orbiter. Ten (10) high chamber pressure bell nozzle type engines were selected for the booster, and two (2) for the orbiter. All boost engines are throttleable. The engines are designed for 100 mission life with a 10 hour life between overhaul.

Figure 3-79 shows the booster engine feed system geometry. Five 14" dia. lines run from the oxidizer tank with each line splitting into two 10" dia. lines. The line division is positioned such that a vapor bubble generated by an engine shut down will not be ingested by another engine. Engine isolation valves are located immediately downstream of the line division. The ten resulting lines are then routed to each boost engine as shown. Diffusers are used to transition smoothly from the 10" dia. lines to the required 14" dia. engine supply. Pressure/volume compensators and gimbal bellows assemblies are used immediately upstream of the engines. The oxidizer tank incorporates anti-vortex and slosh baffles.

The hydrogen feed system is generally similar, except that due to the relative close coupling of the hydrogen tank and the engines, the hydrogen lines are initially fed from a compartmented sump. Engine shutoff valves are located at the sump outlets. The hydrogen tank also incorporates a multi-cruciform anti-vortex baffle assembly and slosh baffles. The compartmented sump and the anti-vortex tank baffle are configured so that any vapor bubble generated by an engine shutdown can not be ingested by another engine. Single point fill/drain vehicle/AGE interfaces are used for each propellant. Initial helium engine requirements are ground supplied. Upon engine start-up, bleed GH_2 and bleed GOX are used to pressurize the hydrogen and oxygen tanks respectively. The boost feed system for the orbiter is similar and is schematically shown by Figure 3-80.

3.3.5.2 Orbiter Maneuvering and Attitude Control Systems - On-orbit maneuvering and attitude control requirements are dictated by the nominal ΔV budget and the required translational and angular acceleration response characteristics. The initial circularization, orbit transfer and retro are performed by the orbit maneuvering system. Gross attitude control during these burns is provided by

CONCEPT "M"
BOOSTER ENGINE FEED SYSTEM

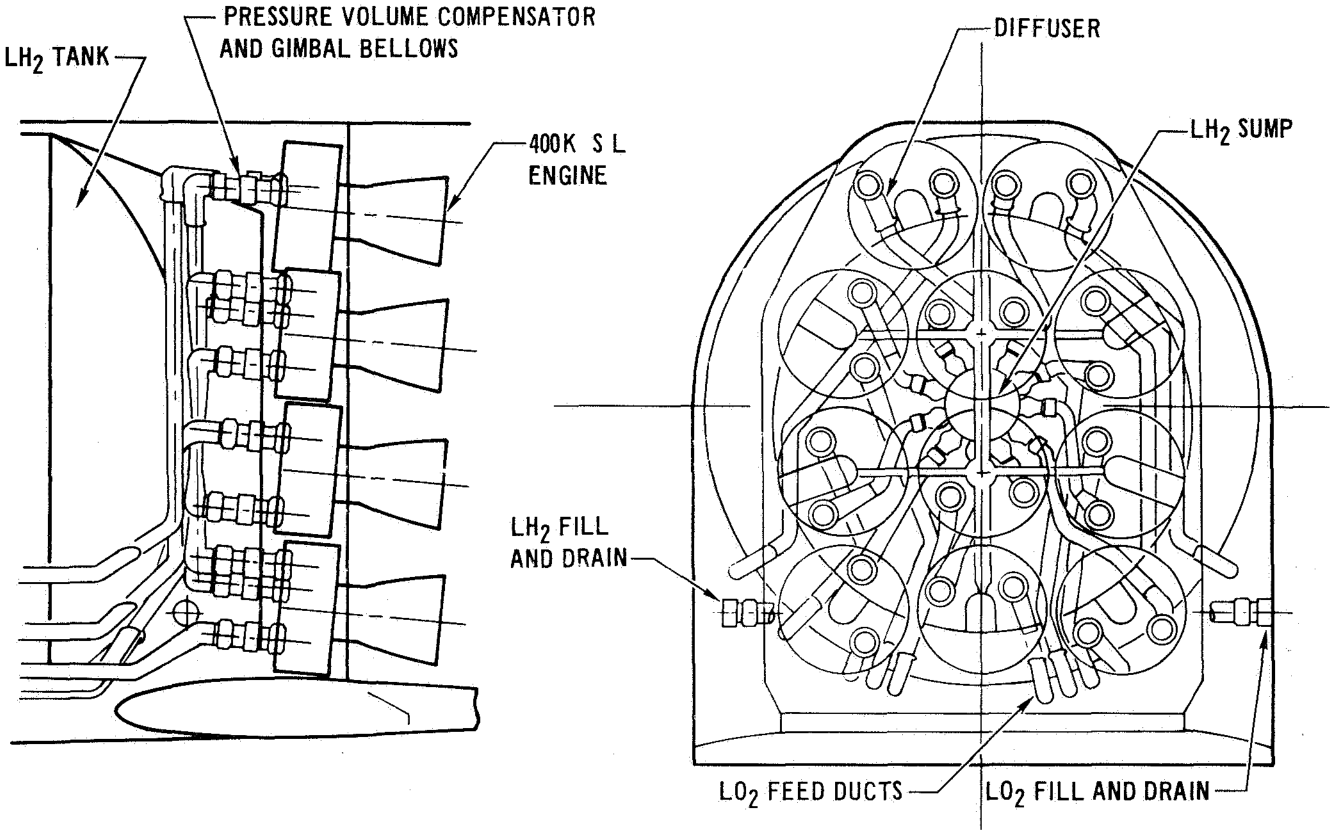


FIGURE 3-79

CONCEPT "M"
ORBITER BOOST ENGINE FEED SYSTEM

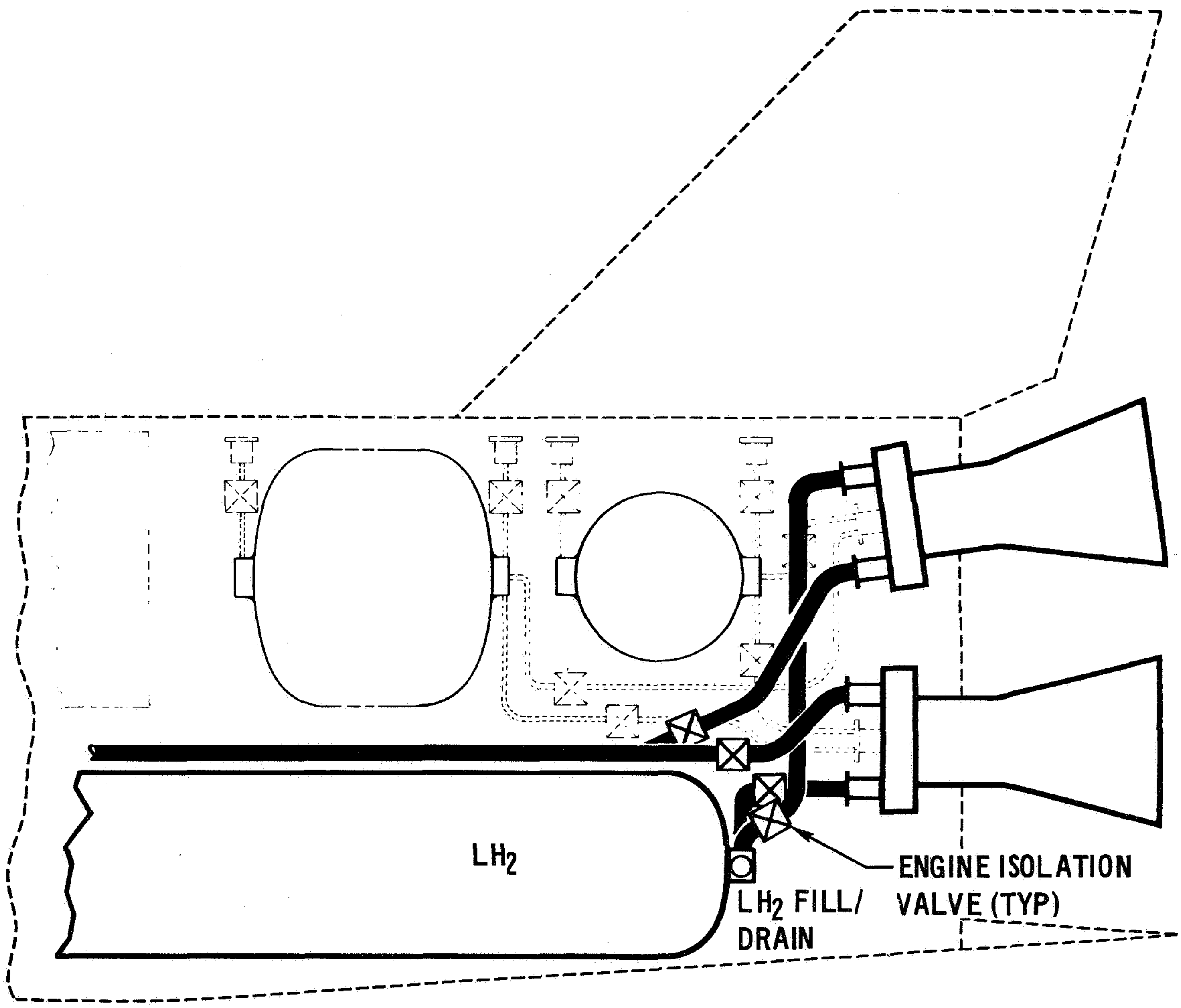


FIGURE 3-80

gimballing the engines. All other orbital and entry translational and attitude maneuvers are performed by the RCS.

The large orbital maneuvers may be satisfied by using one or both of the orbiter boost engines, at reduced thrust level, or by adding an additional engine system, e.g. two additional RL-10 engines. A trade study comparing the weight of possible alternatives was made. The lightest maneuver system is obtained with either the use of an advanced design high Pc bell nozzle engine operating in a pressure fed mode at 1% thrust, or the use of two additional RL-10 engines. The advanced design pressure fed concept has been based on the performance potentially achievable if an engine design could be developed for optimum performance at both 100% and 1% thrust levels. The current design high Pc engine performance is estimated to be approximately 30 seconds lower in Isp, which causes the pressure fed system to be 2000 pounds heavier than the RL-10 installation. Since the advanced design pressure fed and the RL-10 concepts are essentially equal in weight, the pressure fed concept was selected for the baseline design to avoid the installation of additional engines. Figure 3-81 schematically shows the general arrangement of the pressure fed mode orbit maneuvering system. Note that the propellant is drawn from separate cryogenic storage tanks located in the aft section of the orbiter.

The number of RCS engines and the engine thrust levels may, for attitude control, be held to a minimum by utilizing a combination of wing mounted and fuselage mounted engines as shown in Figure 3-82. The translation engines are also used for pitch and yaw attitude control, with roll control provided by additional wing mounted engines. Arrangements without wing mounting were considered but would require additional engines or higher thrust levels to satisfy the yaw and roll requirements.

3.3.5.3 <u>Cruise Propulsion</u> - A subsonic cruise propulsion subsystem is incorporated on both the booster and the orbiter to provide the capability of (1) cruise back to the landing site (booster and orbiter), (2) go-around at the landing site, and (3) cross-country ferrying. In addition, the study requirements were that only off-the-shelf engines using conventional JP fuel were to be considered in detail.

The baseline orbiter cruise propulsion installation can be seen in Figure 3-83. In this configuration four (4) JT8D-9 turbofan engines are mounted within the

CONCEPT "M"
ORBIT MANEUVER FEED SYSTEM

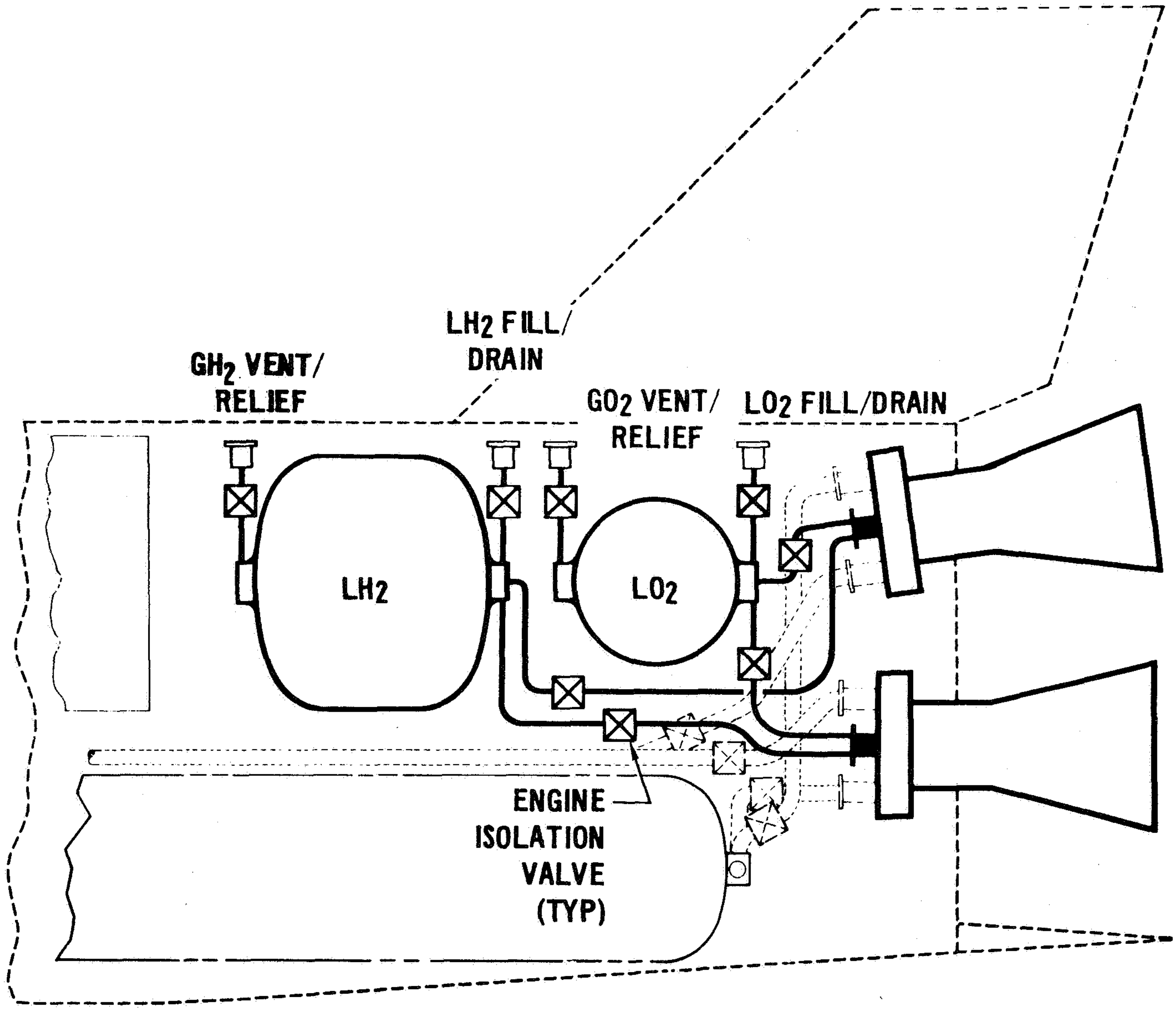


FIGURE 3-81

CONCEPT "M"
RCS ENGINE ARRANGEMENT

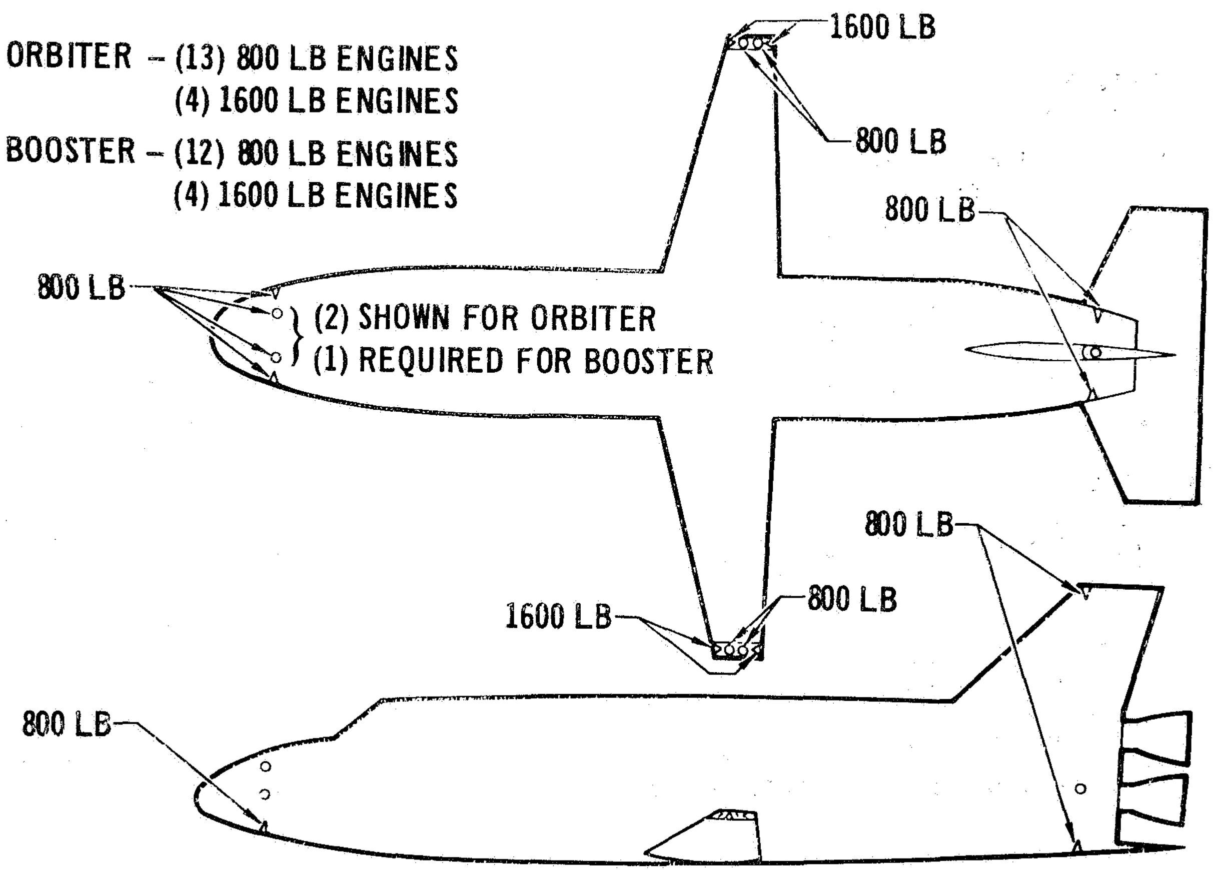


FIGURE 3-82

CONCEPT "M"
INBOARD PROFILE - ORBITER

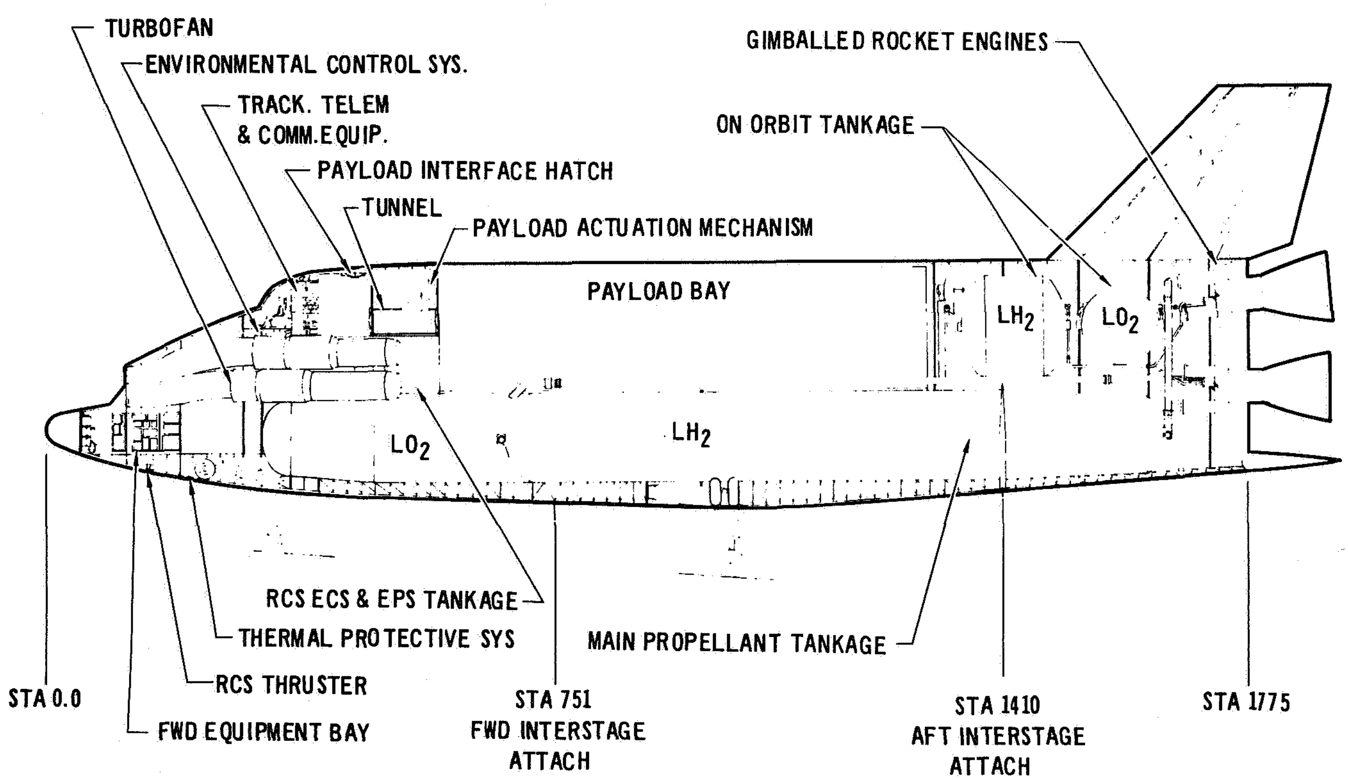


FIGURE 3-83

forward fuselage. The JP fuel is stowed in wing tankage. Doors are installed in each of the four engines inlet ducts to protect the engines from boost and entry heating. The engine duct losses were estimated to be 5%.

The engine exhaust ducts are canted 20° to the vehicle axis. The cosine losses were considered but exhaust scrubbing losses on the side of the vehicle were not evaluated. A detailed study of the effective thrust loss and the effects of noise and vibration induced on the sides of the orbiter should be accomplished in future studies.

Unlike the orbiter, the booster has a long range cruise back requirement. For this reason a significant portion of the system weight is fuel and the operating duration of the engine will be hours instead of minutes. Thus the engine selection for the booster should have the characteristics of low specific fuel consumption rate and significant operating life. The baseline configuration uses six (6) JT3D-7 turbofan engines mounted in the forward fuselage as shown in Figure 3-84.

3.3.6 Weight Analysis - Concept "M" weight summaries for payload capabilities of 12,500 (9 x 34 ft), 25,000 (15 x 60 ft) and 50,000 (15 x 60 ft) lb are presented in Tables 3-15 and 3-16. The data presented for the 12,500 and 25,000 lb payloads is based on the configuration and weight information given in Reference 3.

In the case of the 50,000 lb payload configuration weights were generated by scaling the vehicles and subsystems of the 25,000 lb payload configuration. In both Concept "L" and "S" payload densities were maintained at a constant 4.7 lbs/cu.ft. across the payload range. However, in Concept "M" payload densities were 5.6 lbs/cu.ft. for the 12,500 lb payload case, 2.4 lb/cu.ft. for the 25,000 payload case, and 4.7 lbs/cu.ft. for the 50,000 lb payload configuration.

As in the case of Concept "L" boost engine thrust structure and hydrogen tank insulation weights were removed from the body structure and added to the main propulsion system.

General definition of the concept in terms of its geometric characteristics, material breakdown and component description of various subsystems can be found in Table 3-16.

The weight statement given for the 12,500 pound payload case is considered to be highly optimistic. This configuration was generated early in the NASA-MSC study and is not considered entirely valid. If several adjustments are made

CONCEPT "M"
INBOARD PROFILE - BOOSTER

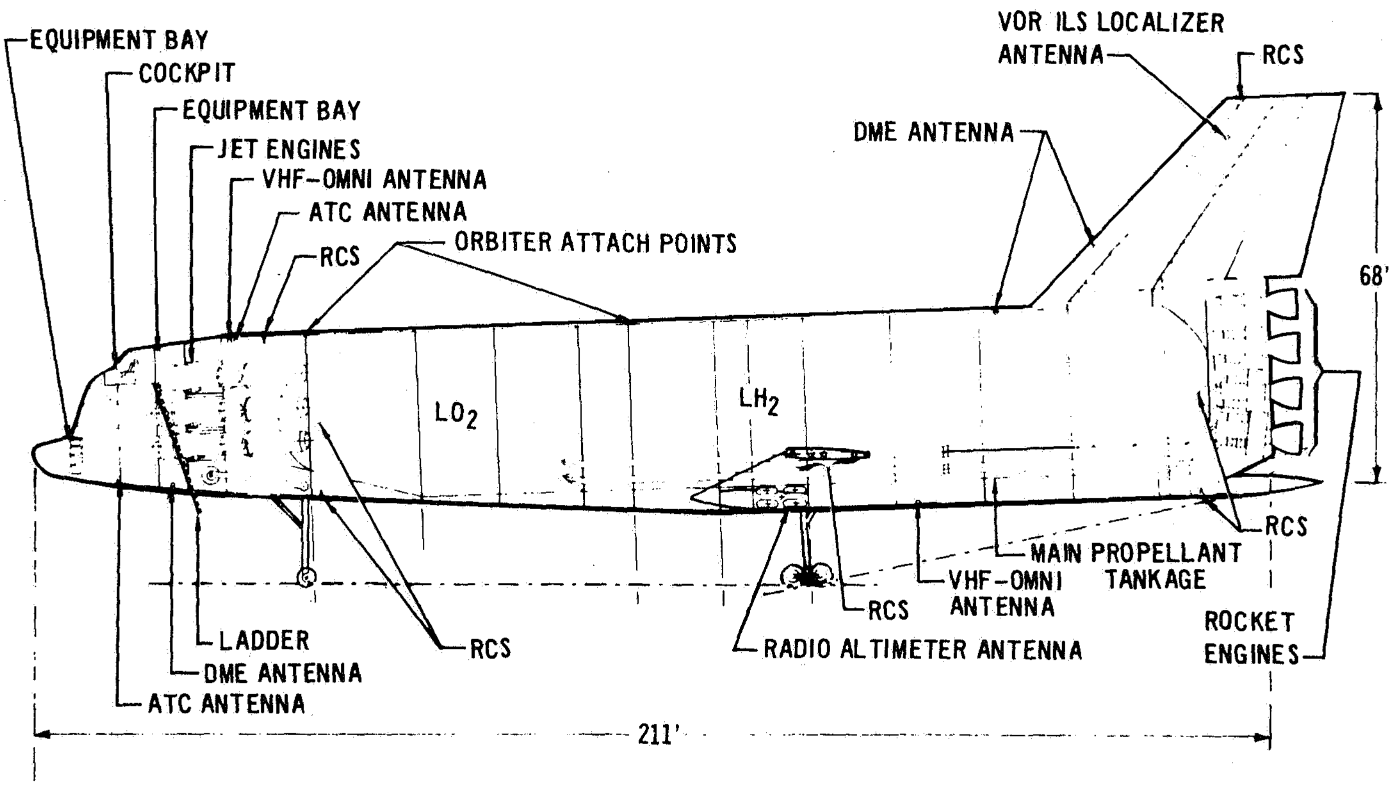


FIGURE 3-84

TABLE 3-15
CONCEPT "M" – ORBITER AND BOOSTER WEIGHT SUMMARY

SUBSYSTEM COMPONENT (LB)	50K PAYLOAD		25K PAYLOAD		12.5K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
BODY STRUCTURE	(31,735)	(106,550)	(31,735)	(69,300)	(17,900)	(36,750)
INTEGRAL TANK	8,399	52,900	8,399	34,400	5,220	18,240
REMAINING BODY STRUCTURE	24,076	53,650	23,336	34,900	14,480	18,510
THERMAL PROTECTION SYSTEM	(16,621)	(39,540)	(16,621)	(25,870)	(8,670)	(12,460)
BODY	13,757	33,150	13,757	21,685	7,180	10,440
AERO SURFACES	2,525	2,790	2,525	1,825	1,320	880
BASE HEAT SHIELD	339	3,600	339	2,360	170	1,140
AERO SURFACES	(21,433)	(82,650)	(21,433)	(54,050)	(8,970)	(18,900)
WING	14,700	57,200	14,700	37,410	7,100	15,120
HORIZONTAL TAIL	4,592	17,450	4,592	11,400	1,280	2,590
VERTICAL TAIL	2,141	8,000	2,141	5,240	590	1,190
LANDING GEAR	(7,750)	(20,400)	(6,400)	(12,750)	(3,800)	(6,600)
MAIN PROPULSION SYSTEM	(35,861)	(151,290)	(24,409)	(104,340)	(14,060)	(48,880)
ENGINES	11,540	57,700	8,892	40,100	5,450	25,100
GIMBALS	1,739	8,660	1,334	6,015	820	2,500
TANK BULKHEADS AND BAFFLES	1,840	14,420	1,840	9,436	1,140	4,900
TANK INSULATION	1,822	6,510	1,822	4,260	1,130	2,930
THRUST STRUCTURE	6,350	21,300	4,140	14,800	2,470	7,450
FEED SYSTEM	6,830	42,700	6,381	29,729	3,050	6,000
ORBIT MANEUVER SYSTEM	(1,775)	–	(1,462)	–	(760)	–
ENGINES	–	–	–	–	–	
TANK	1,775	–	1,462	–	760	–
LINES, VALVES, ETC.	INCL IN ACS	–	INCL IN ACS	–	INCL IN ACS	–
ATTITUDE CONTROL SYSTEM	(3,030)	(4,250)	(2,500)	(3,500)	(1,500)	(1,500)
ENGINES	1,530	2,150	1,260	1,720	760	760
TANK	500	700	410	660	240	240
LINES, VALVES, ETC.	1,000	1,400	830	1,120	500	500
LANDING ASSIST	(17,800)	(49,800)	(14,700)	(30,510)	(7,620)	(17,800)
ENGINES	16,770	43,700	13,850	26,760	7,120	16,800
FUEL TANK	165	5,050	135	3,090	100	820
FEED SYSTEM	865	1,050	715	660	400	180
PRIME POWER SYSTEM	(4,845)	(4,560)	(4,845)	(3,994)	(3,715)	(2,410)
BATTERIES	230	690	230	690	230	690
FUEL CELLS	400	–	400	–	400	–
REACTANT SUBSYSTEM-DRY	367	–	367	–	367	–
REACTANTS	765	–	765	–	765	–
AUXILIARY POWER UNIT	365	1,030	365	730	115	225
FUEL	500	776	500	550	160	170
TANKS, LINES, VALVES	80	140	80	100	30	30
MOUNTING STRUCTURE	72	68	72	68	72	68
INVERTER	160	160	160	160	160	160
CIRCUITRY	1,906	1,696	1,906	1,696	1,416	1,067
HYDRAULICS	(1,150)	(2,960)	(1,150)	(2,100)	(355)	(645)
AERODYNAMIC CONTROLS	(2,700)	(6,550)	(2,700)	(4,650)	(1,000)	(2,300)
AVIONICS	(2,395)	(1,720)	(2,395)	(1,720)	(1,588)	(986)
GUIDANCE AND NAVIGATION	890	410	890	410	590	235
TELECOMMUNICATIONS	325	205	325	205	215	118
CENTRAL MANAGEMENT COMPUTER	180	180	180	180	119	103
DISPLAYS, CONTROL AND SEQUENCING	480	480	480	480	318	275
FLIGHT CONTROL	75	75	75	75	50	43
CONTROL AMPLIFIERS	125	95	125	95	83	54
INSTRUMENTATION	125	125	125	125	83	72
MOUNTING STRUCTURE	195	150	195	150	130	86
ENVIRONMENTAL CONTROL SYSTEM	(1,590)	(430)	(1,590)	(430)	(1,054)	(239)
GAS MANAGEMENT AND PROCESSING	52	–	52	–	35	–
GAS SUPPLY AND CONTROLS	353	–	353	–	232	–
HEAT TRANSPORT	1,022	–	1,022	–	680	–
CREW WATER SUPPLY	11	–	11	–	7	–
HYDRAULIC SYSTEM COOLING	62	126	62	126	40	70
AIR CYCLE	–	28	–	28	–	16
COOLANT LOOP	–	226	–	226	–	125
O_2 SUPPLY	–	25	–	25	–	14
CIRCUITRY LINES, FITTINGS	90	25	90	25	60	14
CREW AND FURNISHINGS	(600)	–	(600)	–	(600)	–
CREW	400	–	400	–	400	–
FURNISHINGS	200	–	200	–	200	–
BALLAST	0	0	0	0	0	
CONTINGENCY	0	0	0	0	0	
MAIN PROPELLANT	(441,530)	(2,827,430)	(435,410)	(1,852,996)	(268,378)	(964,510)
USABLE – BOOST	400,000	2,803,230	400,000	1,837,180	247,830	952,000
ON-ORBIT MANEUVER	30,260	–	25,020	–	13,830	–
RESIDUALS AND PRESSURANT	11,270	24,200	10,390	15,816	6,718	12,510
JET FUEL	(4,330)	(155,300)	(3,670)	(81,200)	(3,200)	(16,400)
USABLE	3,730	153,000	3,070	80,000	1,500	11,400
RESERVE	600	2,300	600	1,200	1,700	5,000
ACS PROPELLANT	(6,840)	(7,350)	(5,650)	(4,500)	(2,440)	(1,620)
PAYLOAD	(45,000)	–	(25,000)	–	(12,500)	–
STAGE LIFT-OFF WEIGHT	641,985	3,460,730	602,270	2,251,910	359,910	1,132,000
GROSS LAUNCH WEIGHT	4,102,715		2,854,180		1,491,910	

TABLE 3-16

CONCEPT "M" – GEOMETRICAL, MATERIAL AND SYSTEM DESCRIPTION DATA

	50 K PAYLOAD		25 K PAYLOAD		12.5 K PAYLOAD	
	ORBITER	BOOSTER	ORBITER	BOOSTER	ORBITER	BOOSTER
LENGTH – FT	148	250	148	211	115	175
PAYLOAD CYLINDER DIMENSIONS – FT	15 DIA X 60	–	15 DIA X 60	–	9 DIA X 35	–
AREAS – SQ FT						
BODY WETTED AREA – OML	12,150	32,400	12,150	23,082	6,891	15,890
EMPENNAGE WETTED AREA						
VERTICAL TAIL	910	2,940	910	2,094	408	1,440
HORIZONTAL TAIL	1,554	4,510	1,554	3,216	472	1,000
WING WETTED AREA	2,692	7,600	2,692	5,408	1,420	3,710
DOOR AREA						
VOLUME – CU FT						
BODY – OML	66,480	273,000	66,480	164,380	31,200	94,000
BODY STRUCTURE WEIGHT (LB)	(31,735)	(106,550)	(31,735)	(69,300)	(19,700)	(36,750)
ALUMINUM	19,075	83,400	19,075	54,300	11,850	28,800
TITANIUM	12,660	23,150	12,660	15,000	7,850	7,950
TPS – WEIGHT (LBS) AREA (SQ FT)						
BODY						
HCF	4,971/6,992	3,730/9,200	4,971/6,992	2,437/6,549	2,590/4,220	1,170/4,500
ADHESIVE	350/6,992	500/9,200	350/6,992	326/6,549	180/4,220	160/4,500
TITANIUM	1,095/1,217	18,700/19,070	1,095/1,217	12,232/13,586	570/735	5,900/9,350
HC PANEL AND TITANIUM BACKUP	3,557/4,381	4,230/5,570	3,557/4,381	2,766/3,973	1,860/2,650	1,330/2,730
MICROQUARTZ	4,123/12,149	9,600/28,200	4,123/12,149	6,284/20,135	2,150/7,350	3,020/13,830
AERO SURFACES						
HCF	2,385/2,803	2,450/6,050	2,385/2,803	1,610/4,308	1,247/1,690	776/2,960
ADHESIVE	140/2,803	330/6,050	140/2,803	215/4,308	73/1,690	104/2,960
AERO SURFACES – WEIGHT (LB)						
WING						
TITANIUM	13,300	54,300	13,300	35,460	6,420	14,340
CARBON-CARBON (LEADING EDGE)	1,400	2,900	1,400	1,950	680	780
HORIZONTAL TAIL						
TITANIUM	3,652	15,760	3,652	10,300	1,020	2,340
CARBON-CARBON (LEADING EDGE)	940	1,690	940	1,100	260	750
VERTICAL						
TITANIUM	1,691	6,890	1,691	4,509	470	1,020
CARBON-CARBON (LEADING EDGE)	450	1,110	450	731	120	170
MAIN PROPULSION						
TANK BULKHEADS & BAFFLES –						
ALUMINUM – WEIGHT (LB)	1,840	14,420	1,840	9,436	1,140	4,900
TANK INSULATION						
POLYURETHANE FOAM-WEIGHT (LBS)/AREA (SQ FT)	1,844/4,613	6,510/16,500	1,822/4,613	4,260/10,800	1,130/2,860	2,930/7,420
THRUST STRUCTURE						
TITANIUM – WEIGHT (LB)	4,430	21,300	4,140	14,800	2,470	7,450
ENGINE DESCRIPTION						
TYPE	HIGH PC BELL	HIGH PC BELL		HIGH PC BELL		HIGH PC BELL
NUMBER	2	10	2	10	2	9
THRUST PER ENGINE – (LB)	635,000 (VAC)	635,000 (VAC)	463,000 (VAC)	400,000 (SL)	250,000 (VAC)	234,000 (VAC)
PROPELLANT TYPE	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
ORBIT MANEUVER SYSTEM						
TANK						
ALUMINUM – WEIGHT (LB)	1,775	–	1,462	–	760	–
VOLUME – CU FT	1,180	–	975	–	540	–
PROPELLANT TYPE	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
ATTITUDE CONTROL SYSTEM						
TANK						
ALUMINUM – WEIGHT (LB)	500	700	410	660	240	240
VOLUME – CU FT	320	345	265	212	115	115
ENGINE DESCRIPTION						
TYPE						
NUMBER/THRUST PER ENGINE-LB (VAC)	13/960	12/1,500	13/800	12/800	13/350	13/350
NUMBER/THRUST PER ENGINE-LB (VAC)	4/1,920	4/3,000	4/1,600	4/1600	4/700	4/700
PROPELLANT TYPE	LOX/LH_2	LOX LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
LANDING ASSIST						
TANK – BLADDER TYPE						
VOLUME – CU FT	99	3,550	84	1,855	73	374
ENGINE DESCRIPTION						
TYPE	TURBOFAN	TURBOFAN	TURBOFAN	TURBOFAN	TURBOFAN	TURBOFAN
NUMBER	4	6	4	6	2	4
THRUST PER ENGINE – LB (SLS)	17,400	27,600	14,500	17,000	12,000	12,000
FUEL TYPE	JP	JP	JP	JP	JP	JP
PRIME POWER SYSTEM						
BATTERIES (AgO–Zn)						
ENERGY PER BATTERY – KWH	6	6	6	6	6	6
NUMBER	2	6	2	6	2	2
FUEL CELL						
POWER OUTPUT PER FUEL CELL – KW	2.0–2.5	–	2.0–2.5	–	2.0–2.5	–
NUMBER	4	–	4	–	4	–
AUXILIARY POWER UNIT						
NUMBER	3	4	3	4	2	3
ENVIRONMENTAL CONTROL SYSTEM						
NUMBER OF CREW	2	–	2	–	2	–
MISSION DURATION – DAYS	7	–	7	–	7	–

relative to certain components as indicated below, the overall effect would increase the dry weight of the orbiter by 24%, increase the dry weight of the booster by 31% and increase the total gross launch weight by 30%.

Item	Ref. Design	Proposed Adjustments
Booster Body Structure Unit Wt. - psf	2.3	3.0
Booster Horizontal Tail Area - ft^2	1,000	2,210
Orbiter Horizontal Tail Area - ft^2	472	820
Orbiter Total volume - ft^3	31,400	44,000
Orbiter payload size - ft	9' dia. x 35' long	15' dia. x 15' long

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3.4 Subsystem Descriptions - The purpose of this section of the report is to describe the functional aspects and baseline characteristics of those subsystems which are common to each spacecraft concept analyzed during this study. These include Electrical Power, Hydraulic Power and Flight Controls, Environmental Control and Life Support and Integrated Avionics. Although these subsystems were identical, in design concept, for each spacecraft configuration, there were slight differences due to differences in individual study constraints. These differences are noted herein and are reflected in the weight statements given in Section 3.1.6.

Review of subsystem requirements for both the orbiter and booster indicates that a large degree of commonality in system characteristics is practical as well as desirable. System commonality between stages is desirable from the standpoint of flight and ground crew familiarization, maintenance requirements and logistics needs. The varying facets of these systems are discussed in the subsequent subsections.

3.4.1 Electrical Power - The characteristics of the electrical power subsystems for both the booster and the orbiter are described in this section. The energy requirements and selected baseline power sources for the baseline vehicles are as follows:

Vehicle	Energy Required	Selected Power Source
Booster	21.5 KWH	AgO-Zn Batteries
Orbiter	805.8 KWH	H_2-O_2 Fuel Cells with Peaking/Emergency AgO-Zn Batteries

3.4.1.1 Electrical Power Requirements - A seven day mission was used as a baseline for the orbiter load analysis. The mission consists of 26 hours for pre-launch through ascent and initial docking, 120 hours orbital operation, and 24 hours for return, descent and landing. The orbiter load summary is shown in Figure 3-85. The total energy required for the mission is 805.8 KWH for Concepts "S" and "M" and 589.3 KWH for Concept "L". The overall average main bus power is 4.74 KW for Concepts "S" and "M" and 3.46 KW for Concept "L", with peaks of 6.94 KW during rendezvous and docking operations. Figure 3-86 shows the variation in main bus average power for the various mission phases.

The baseline mission for the booster consists of 2 hours for prelaunch, 10 minutes for liftoff through jet engine start, and 2 hours for cruise through landing. The booster load summary is shown in Figure 3-87. The booster requires

ORBITER ELECTRICAL LOAD SUMMARY
(Electrical Energy in Watt Hours)

EQUIPMENT \ MISSION PHASE	PRELAUNCH 2 HOURS	ASCENT 1 HOUR	ORBITAL PHASING 20 HOURS	RENDEZVOUS & DOCKING 3 HOURS	ORBITAL OPERATIONS 120 HOURS	RETURN PHASING 22 HOURS	ENTRY & LANDING 2 HOURS
Inertial Sensors	1500	750	15,000	2,250	90,000	16,500	1,500
Computers	2,200	1,100	22,000	3,300	132,000	24,200	2,200
Flight Control Amplifiers	740	408	600	110	1,800	825	713
3-Axis Rate Gyros	90	45	900	135	5,400	990	90
Communications	525	355	5,670	1,050	32,020	4,088	635
Rendezvous Radar	--	--	--	800	5,600	--	--
Displays & Controls	2,670	1,335	27,500	4,179	163,786	30,720	2,750
Navigation Aids	--	--	800	120	4,800	880	--
Landing Aids	--	--	--	--	--	--	644
Data Handling	540	350	5,400	810	32,400	5,940	540
TV Cameras	--	--	160	80	960	175	80
EC/LS	1,218	609	12,180	1,822	36,500	13,410	1,218
Lighting	500	250	5,000	750	15,000	5,500	500
Misc. & Losses	599	312	5,713	924	31,216	6,194	652
Total Energy (W-H)	10,582	5,514	100,923	16,330	551,482	109,422	11,522
Average Power (W)	5,291	5,514	5,046	5,443	4,596	4,974	5,761

Total Energy for 7 Day Mission 805.8 KWH

Average Power for 7 Day Mission 4.74 KW

Peak Power (During Rendezvous & Docking) 6.94 KW

FIGURE 3-85

ORBITER MAIN BUS AVERAGE POWER
Total Mission Energy: 805.8 KWH

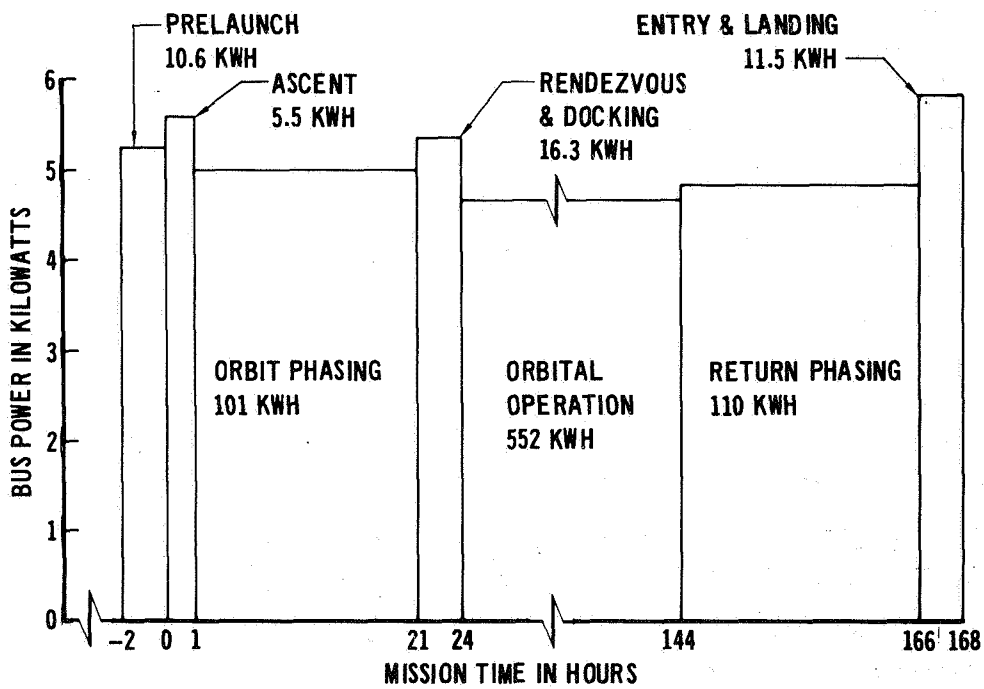

FIGURE 3-86

BOOSTER ELECTRICAL LOAD SUMMARY
(Electrical Energy in Watt-Hours)

EQUIPMENT \ MISSION PHASE	PRELAUNCH 2 HOURS	ASCENT 10 MINUTES	CRUISE & LANDING 2 HOURS
Inertial Sensors	1,500	125	1,500
Computers	2,200	183	2,200
Flight Control Amplifiers	740	62	683
3-Axis Rate Gryos	90	7	90
Communications	525	61	635
Displays & Controls	2,830	243	2,910
Landing Aids	--	--	544
Data Handling	380	32	380
TV Cameras	--	7	80
EC/LS	988	82	988
Lighting	125	11	125
Misc. & Losses	563	49	608
Total Energy	9,941 W-HR	862 W-HR	10,743 W-HR
Average Power	4,970 W	5,172 W	5,372 W

Total Mission Energy 21.5 KWH

Average Mission Power 5.2 KW

Peak Power (During Cruise and Landing) 5.83 KW

FIGURE 3-87

21.5 KWH of energy to perform its mission. The average power level is 5.2 KW, with 5.83 KW peaks during cruise and landing. The variation of main bus average power with respect to booster mission phase is shown in Figure 3-88.

All power quantities used in the load analyses were based on a 28 VDC bus. Inversion losses were added for equipment operating on AC.

The electrical power required for operation of the main propulsion engines has not been included in the load summaries. This power (6.2 KVA @ 115V 400 Hz per engine) will be supplied by turbine driven auxiliary power units (APU). These units also provide backup hydraulic power for engine gimbal and prime hydraulic power for the aerodynamic control surface prior to turbojet operation.

3.4.1.2 Electrical Power Subsystem (EPS) Baseline - The baseline electrical power subsystem configurations for the orbiter and the booster are described in the following paragraphs. The main power sources for the orbiter are H_2-0_2 fuel cell modules. For the booster, rechargeable Ag0-Zn batteries are used. Except for the power sources, the subsystems are essentially identical for both the orbiter and booster.

Figures 3-89 and 3-90 shows the EPS configurations for the orbiter and booster, respectively. The design philosophy used is an adaptation of that used in the design of commercial aircraft such as the DC-9 and the DC-10. The components of the EPS (for both orbiter and booster) are interconnected to form two separate power source channels. These prime source channels can be operated either independently, or in parallel. Paralleling of the DC buses is accomplished by closing the DC bus tie relay No. 3 (DCBTR3), and the AC buses can be paralleled by closing the AC bus tie relay No. 3 (ACBTR3). The inverters are timed by a common clock located in the inverter frequency reference. This common clock synchronizes the inverters so parallel operation is possible. The inverter frequency reference contains sufficient redundancy to maintain the desired system reliability.

Both the DC and the AC buses are further divided into essential and non-essential buses. Only that equipment that is absolutely essential for crew and vehicle survival is connected to the essential buses - all other equipment is connected to the non-essential buses. Although circuit protection components are not shown, unprotected circuits will be kept to an absolute minimum consistent with safety.

BOOSTER MAIN BUS AVERAGE POWER
Total Mission Energy: 21.5 KWH

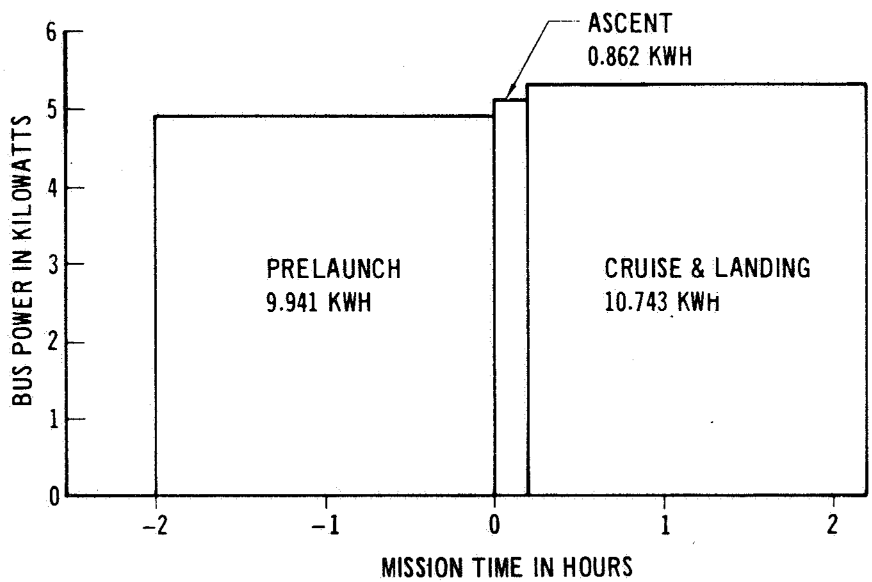

FIGURE 3-88

ORBITER ELECTRICAL POWER SUBSYSTEM

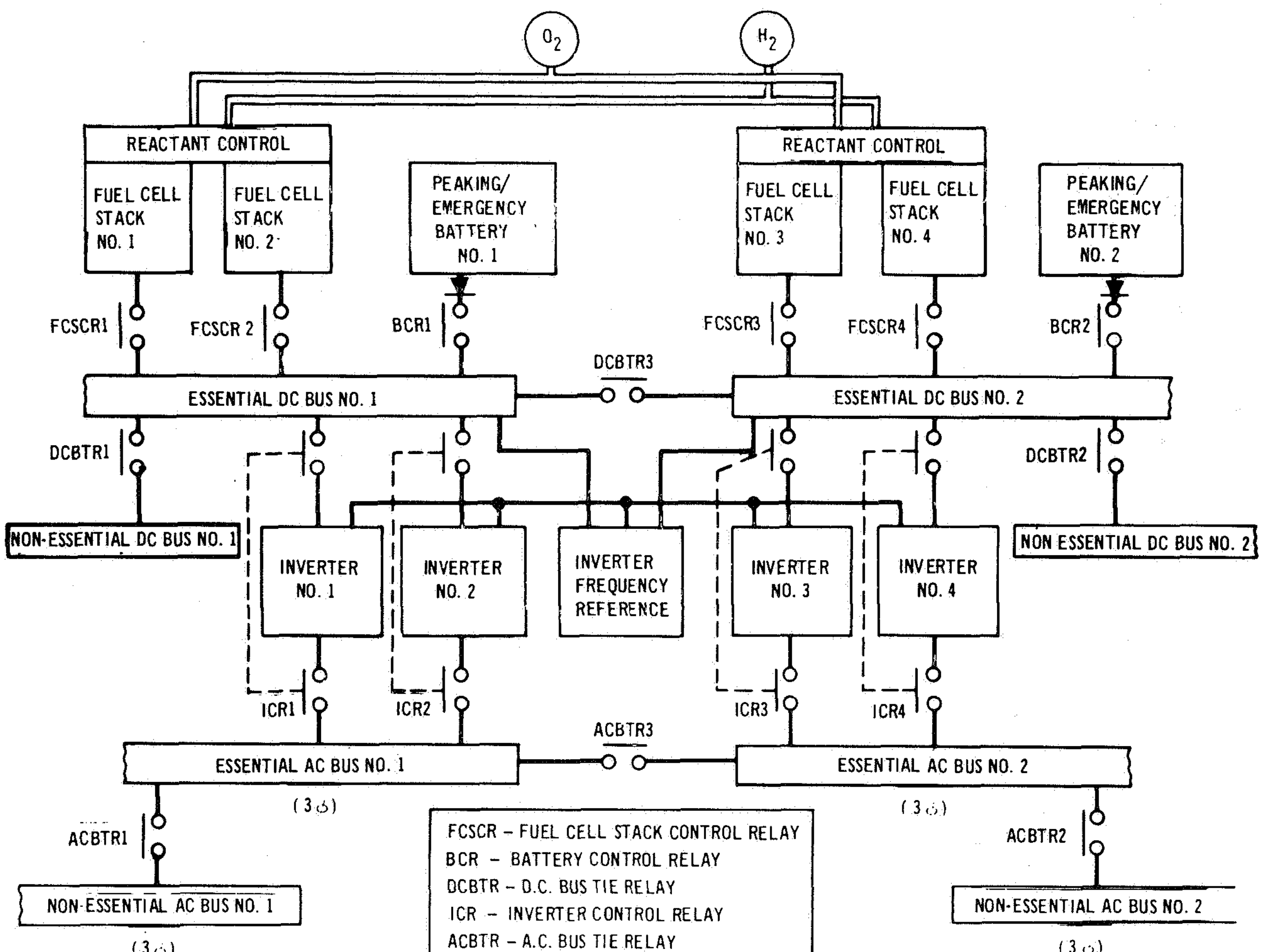

FIGURE 3-89

BOOSTER ELECTRICAL POWER SUBSYSTEM

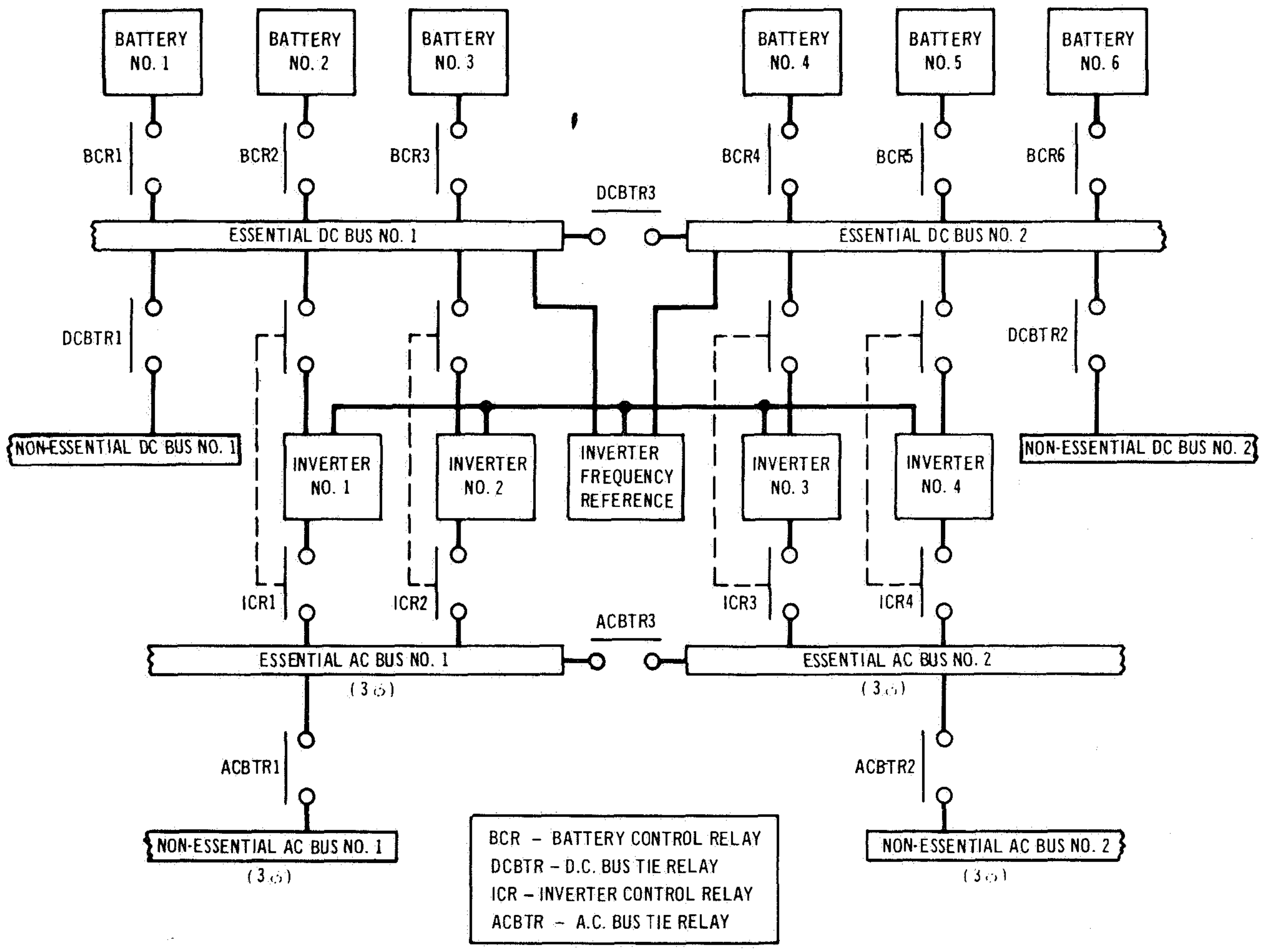

FIGURE 3-90

Orbiter Power Source - Prime power for the orbiter is supplied by four H_2-0_2 matrix type fuel cell modules. Echh module is rated at 2.0 - 2.5 KW, for a total capability of 8-10 KW at the buses. All four fuel cell modules are operated simultaneously for reactant economy as well as continuity of power in the event of a module failure. The peaking/emergency batteries are rated at 6.0 KWH each. These serve two purposes, (1) they improve the bus transient response characteristics (the battery voltage is slightly below the nominal bus voltage), and (2) they will provide up to two hours power for emergency deorbit, entry and cruise in the event of a catastrophic failure of the fuel cell system.

The orbiter power source is sized so that a safe return is possible with two fuel cell modules failed.

Figure 3-91 shows the major components for the orbiter EPS (excluding mounting provisions and radiators).

3.4.1.3 Booster Power Source - Prime power for the booster is supplied by six 6.0 KWH rechargeable Ag0-Zn batteries, for available energy totaling 36 KWH. The battery control relays (BCR) are reverse current sensing, as well as control relays, to prevent degradation of the remaining batteries in the event of a battery failure.

The booster power source is sized so that the mission can be completed with two battery failures.

Figure 3-92 shows the major components for the booster EPS (excluding mounting provisions).

3.4.1.4 Alternate Concepts - During the course of these studies, several different power sources were investigated for potential use in the space shuttle vehicle. These are listed in Figure 3-93 along with the advantages and disadvantages of each candidate.

A turboalternator power source may be competitive with batteries for the booster, due to the relatively short flight duration. This is especially true if the same turbines are used to drive hydraulic pumps as well as alternators. Further study is required in this area with more complete analysis of the electrical and hydraulic load requirements.

ORBITER MAJOR EPS COMPONENTS

ITEM	QTY.
Fuel Cell Module	4
Reactant Control Assy.	2
Thermal Control Unit	1
Product Water Subsystem	1
Control Subsystem	1
Hydrogen Tank	1
Hydrogen	-
Oxygen Tank	1
Oxygen	-
Inverter	4
Peaking/Emergency Battery	2
Power Distribution Subsystem	-

Figure 3-91

BOOSTER MAJOR EPS COMPONENTS

ITEM	QTY.
200 A-H AgO-Zn Battery	6
Inverter	4
Power Distribution	-

Figure 3-92

CANDIDATE ELECTRICAL POWER SOURCES

POWER SOURCE	ADVANTAGES	DISADVANTAGES
AgO–Zn BATTERIES (RECHARGEABLE)	• FLIGHT PROVEN • RELIABLE • REUSEABLE • DEVELOPED • SELF CONTAINED	• WEIGHT AND VOLUME INCREASE ESSENTIALLY LINEARLY WITH REQUIRED ENERGY (55–60 WATT-HOURS PER POUND AND 3–5 WATT HOURS PER CUBIC INCH) • RECHARGE PROCEDURE IS COMPLEX WHEN LARGE NUMBER OF BATTERIES ARE INVOLVED. • WET-LIFE LIMITED (1 YEAR OR LESS)
Ni-Cd BATTERIES	• FLIGHT PROVEN • RELIABLE • REUSEABLE • DEVELOPED • SELF CONTAINED	• WEIGHT AND VOLUME INCREASE ESSENTIALLY LINEARLY WITH REQUIRED ENERGY (10–12 WATT-HOURS PER POUND AND 1–1.5 WATT-HOURS PER CUBIC INCH). • RECHARGE PROCEDURE IS COMPLEX WHEN LARGE NUMBER OF BATTERIES ARE INVOLVED.
H_2–O_2 FUEL CELLS	• CONCEPT FLIGHT PROVEN • RELIABLE • REUSEABLE • LONG OPERATING LIFE – CURRENT LIFE 3000 HOURS, DESIGN GOAL 10,000 HOURS • HIGH ENERGY DENSITY (400–450 WATT-HOURS PER POUND, INCLUDING TANKAGE FOR ORBITER ENERGY AND POWER RANGE)	• HIGH PURITY CRYOGENIC REACTANTS REQUIRE TANKAGE SEPARATE FROM PROPULSION REACTANTS • LIMITED TO DC GENERATION. • MATRIX TYPE FUEL CELLS REQUIRE FLIGHT QUALIFICATION.
TURBOALTERNATOR (H_2–O_2 FUEL)	• LIGHT WEIGHT EQUIPMENT • FUEL SOURCE CAN BE COMMON WITH MAIN PROPULSION TANKS • OPTION OF AC OR DC GENERATION • OPTION OF HIGH OR LOW VOLTAGE GENERATION	• HIGH FUEL CONSUMPTION (2.5–4 POUNDS PER KWH) • COMPLEX CONTROL SYSTEM. • TURBINE EFFICIENCY IS POWER SENSITIVE. • TURBINE EFFICIENCY IS ALTITUDE SENSITIVE. • EXHAUST GAS CAN CAUSE VEHICLE ATTITUDE CHANGE • SHORT DEMONSTRATED OPERATING LIFE (250 HOURS) • DEVELOPMENT REQUIRED.
TURBOALTERNATOR (MONOPROPELLANT HYDRAZINE WITH CATALYST BED)	• LIGHT WEIGHT EQUIPMENT • CONTROL LESS COMPLEX THAN H_2–O_2 UNIT • OPTION OF AC OR DC GENERATION • OPTION OF HIGH OR LOW VOLTAGE GENERATION	• HIGH FUEL CONSUMPTION (5–10 POUNDS PER KWH). • SEPARATE FUEL TANK REQUIRED. • TURBINE EFFICIENCY IS POWER SENSITIVE • TURBINE EFFICIENCY IS ALTITUDE SENSITIVE • EXHAUST GAS CAN CAUSE VEHICLE ATTITUDE CHANGE • SHORT DEMONSTRATED OPERATING LIFE (250 HOURS) • DEVELOPMENT REQUIRED.

FIGURE 3-93

3.4.2 Hydraulic Power and Flight Controls - Evaluation of the various system operational requirements in both stages indicates the need for hydraulic power similar to current large aircraft. In addition, the size of ILRV vehicles coupled with hypersonic control requirements dictate use of full power flight control systems. This size and complexity indicates selection of "fly-by-wire" design which also lends itself to hydraluic system application. This basic approach does not require development of new technology but will permit incorporation of any desirable advances in state-of-the-art during design phase.

3.4.2.1 Hydraulic System Description - The hydraulic systems in both orbiter and booster stage vehicles will be similar in design to preserve stage to stage commonality was well as simplify pilot and maintenance familiarization procedures.

Each stage hydraulic system is designed to achieve the same level of safety and reliability demonstrated by systems on the latest generation of commercial jet aircraft as exemplifed by the McDonnell Douglas DC-8, DC-9 and DC-10.

Three completely independent hydraulic subsystems will supply the flight controls in order that adequate power is available for continued safe flight in the event of a dual hydraulic failure. This concept is shown in Figure 3-94. Each system is powered by a variable displacement, pressure compensated piston-type pump or pumps, and will have separate reservoirs, filters, relief valves and control valves. Where possible identical system components will be used in both stages. Contamination tolerance requirements of components will require careful evaluation during detail component design to maintain necessary system cleanliness and provide required reliability. Adequate provisions must be incorporated to prevent hydraulic pressure surges and system resonance from exceeding safe limits.

These systems will be power balanced and use a minimum number of components thus providing maximum reliability. Parallel arrangement of systems provides expeditious back-up capability in the event of single or double system failure. Power balancing the three systems enhances reliability by minimizing the peak and average loads on any one system and permits the use of smaller, more nearly identical system components. This will also simplify maintenance and reduce logistic requirements.

Hydraulic power transfer units will mechanically interconnect the systems and provide an alternate source of power when one system is unpressurized. Use of the Power Transfer Units (PTU) will vastly reduce required cockpit actions in the event of failure in a specific system since the PTU can take over automatically.

HYDRAULIC SYSTEM OPERATION

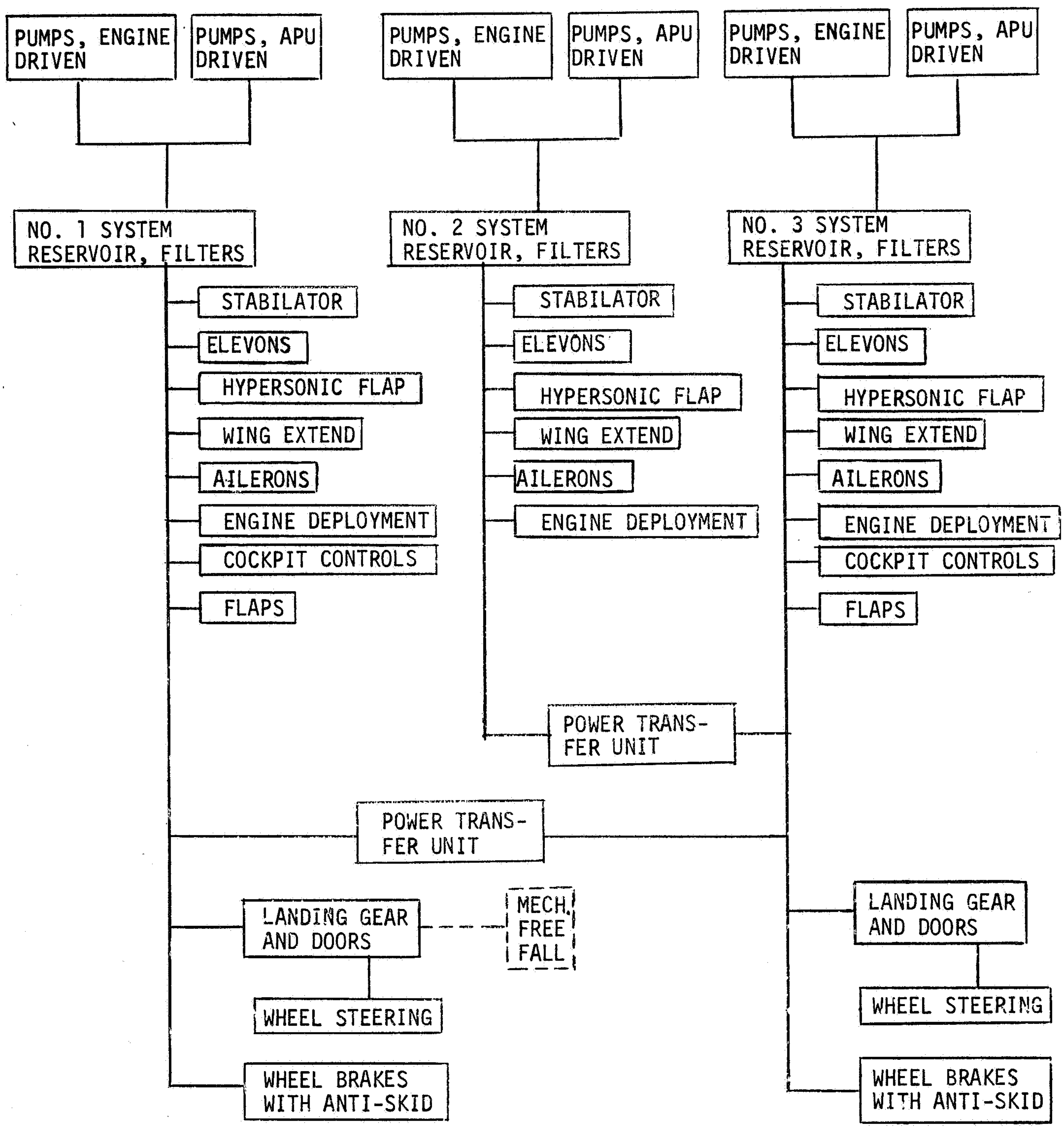

FIGURE 3-94

3.4.3 Environmental Control System - The function of the Environmental Control System (ECS) is to provide a habitable shirtsleeve environment in the vehicle. The orbiter requires an ECS that will provide this environment for two men for a flight as long as seven days. The booster requires an ECS that will provide the desired environment for a brief launch flight or a long ferry flight. The systems to provide these functions are discussed below. The functional concepts and baseline characteristics are given in Figures 3-95 and 3-96 respectively.

3.4.3.1 Orbiter ECS - The functions to be provided by the ECS are: atmosphere supply, atmosphere processing, cabin and equipment temperature control, water supply and waste management. Figure 3-96 gives the baseline system characteristics. The ECS consists of the gas supply and control, the gas processing, the heat transport circuit, the water and waste management, and hydraulic cooling subsystems. These subsystems are briefly described below and with the exception of the hydraulic cooling subsystem, are shown schematically in Figure 3-97.

a. Gas Supply and Control - This subsystem supplies the oxygen and nitrogen for breathing and cabin pressurization. The ECS oxygen is provided by supercritical cryogenic oxygen tanks which supply both the fuel cell and the ECS requirements. Three tanks are provided, any two of which carry ample oxygen for the complete mission. Thus one tank failure will not prevent the accomplishment of a complete mission. In the event of a second failure the third tank contains more than enough oxygen for a safe return to earth. Three supercritical cryogenic nitrogen tanks provide 148 lbs of nitrogen for crew compartment leakage and pressurization with the same redundancy features as the oxygen supply subsystem. The cabin pressure is maintained at 14.7 psia by a cabin pressure regulator which is supplied from either the nitrogen or the oxygen supply. Initially, if the oxygen partial pressure is below the upper limit (3.1 psia), the solenoid valves in the nitrogen supply remain closed and only oxygen is added to the cabin. When the oxygen partial pressure reaches 3.1 psia, the controller opens the solenoid valves (redundant). The nitrogen which is regulated to 150 psig, then backpressures a check valve in the 100 psig oxygen supply line, closing it, so that only nitrogen is supplied. When the oxygen partial pressure drops to the lower limit (2.7 psia) the nitrogen valves are closed and oxygen is again supplied.

ENVIRONMENTAL CONTROL SYSTEM FUNCTIONAL CONCEPT

MISSION PHASE	ORBITER	BOOSTER
PRELAUNCH	SYSTEM COOLING BY AIR CYCLE – GROUND SUPPLY HIGH PRESSURE AIR.	SYSTEM COOLING BY AIR CYCLE – GROUND SUPPLY HIGH PRESSURE AIR.
LAUNCH/ ASCENT	SYSTEM COOLING BY WATER BOILER.	SINK HEAT IN COMPONENTS, COOLANT CIRCUIT.
ORBIT	SYSTEM COOLING BY SPACE RADIATOR–CRYOGENIC GAS SUPPLIES – CO_2 ABSORPTION BY LiOH – CREW WATER FROM FUEL CELLS.	NOT APPLICABLE.
ENTRY	SYSTEM COOLING BY WATER BOILER.	NOT APPLICABLE.
CRUISE/ LANDING	SYSTEM COOLING BY AIR CYCLE – ENGINE BLEED SUPPLIES HIGH PRESSURE AIR.	SYSTEM COOLING BY AIR CYCLE – ENGINE BLEED SUPPLIES HIGH PRESSURE AIR

FIGURE 3-95

ENVIRONMENTAL CONTROL SYSTEM CHARACTERISTICS

REQUIREMENTS	BASELINE SYSTEM
• SHIRT SLEEVE ENVIRONMENT FOR TWO MAN CREW. • SEVEN DAYS IN ORBIT. • CAPABLE OF SUBSONIC FERRY FLIGHT. • DISSIPATE 5^+ KW EQUIPMENT WASTE HEAT. • PROTECT RADIATOR FROM BOOST/ENTRY HEATING.	• SEA LEVEL ATMOSPHERE – NO PRESSURE SUITS. • STORE GASES AS SUPERCRITICAL CRYOGEN. • CONTROL CO_2 WITH LITHIUM HYDROXIDE. • CONTROL EQUIPMENT TEMPERATURES WITH LIQUID COOLANT CIRCUIT AND COLDPLATES. • AIR CYCLE COOLING PACKAGE FOR FERRY/ CRUISE. • DISSIPATE WASTE HEAT WITH SPACE RADIATOR AND WATER BOILER. • RADIATOR ON PAYLOAD BAY DOOR INNER SURFACE. • SUPPLY DRINKING WATER FROM FUEL CELLS. • VAPORIZE LIQUID WASTE – STORE DRIED WASTES • HYDRAULIC COOLING BY RAM AIR.

FIGURE 3-96

ORBITER ECS SCHEMATIC

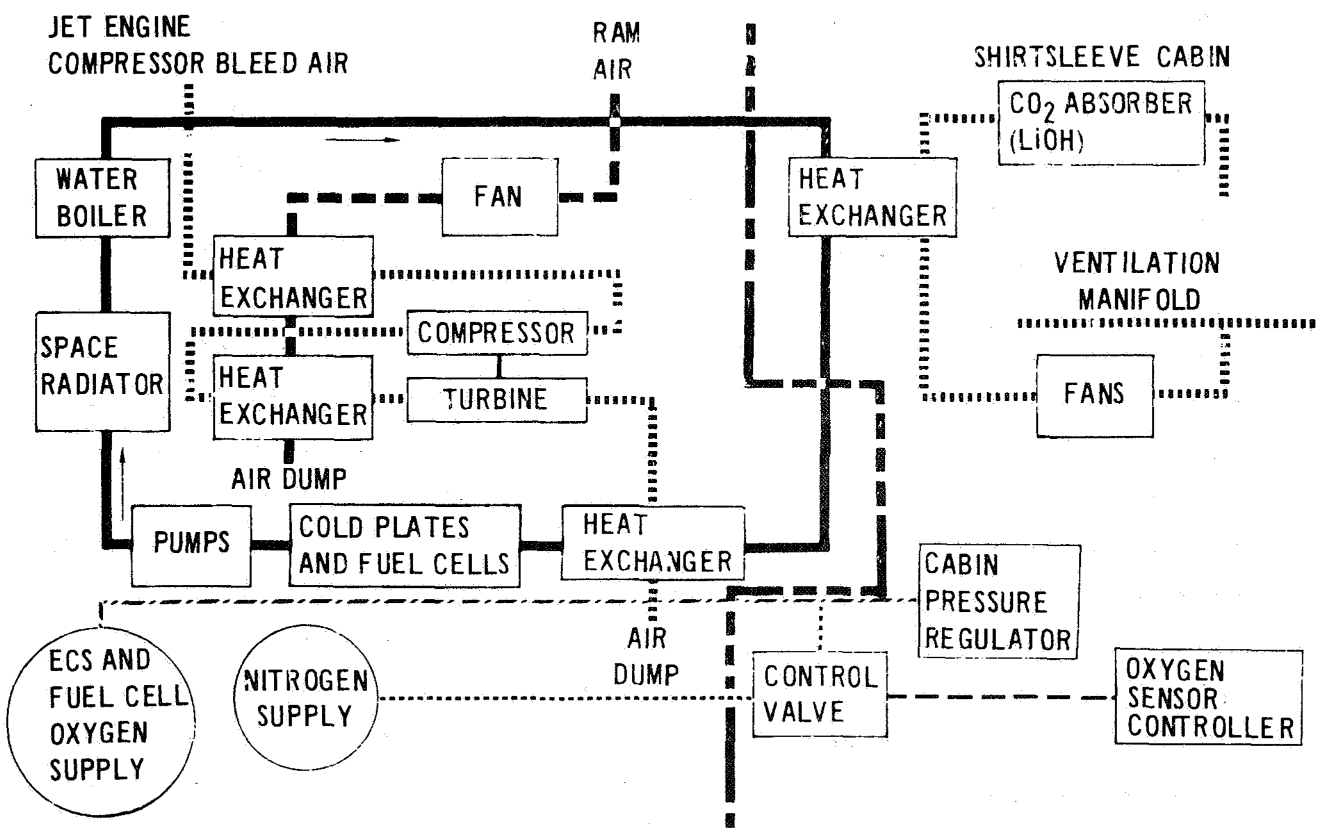

FIGURE 3-97

b. Gas Processing - The system provides crew ventilation, atmosphere constituent control and atmosphere cooling. Cabin fans and gas inflow and outflow distribution ducts are provided at selected locations to circulate the cabin atmosphere. The cabin atmosphere gases are circulated through system components to filter, remove the carbon dioxide by reaction with LiOH, remove odors and trade contaminants with activated charcoal, and cool and control the relative humidity with a condensing heat exchanger.

c. The Heat-Transport Circuit - The system uses redundant coolant loops, and dual coldplates for the thermal control of electronic equipment, a space radiator, and a water boiler for heat dissipation. The secondary loop is used if a failure occurs in the primary loop. Redundant coolant pumps in each loop circulate the heat transfer coolant. Waste heat is rejected by the spacecraft radiator and water boiler in orbit and by the water boiler during atmospheric entry. An air cycle refrigeration package removes waste heat during subsonic cruise flight or during ferry flights.

d. Water and Waste Management - The subsystem provides: drinking water to the crew; a source of water for heat dissipation by evaporation, storage and disposal of condensate from the cabin heat exchanger and fuel cell product water; collection, storage or disposal of waste materials generated during the mission. Because of the short flight mission, water condensed in the cabin heat exchanger/water separator does not supplement the drinkable water supply, but is routed directly to the water boilers. The water supplied by the fuel cells is temporarily stored in a bladder type tank until it is used for drinking or heat dissipation. The fecal wastes, and urine are deposited in zero g, commode type receptacles from which they are automatically transported in a slurry form to an evaporator. The vapors are dumped overboard and the residue is dried for disposal at the end of the mission.

e. Hydraulic Cooling - This subsystem prevents overheating of the fluid in the hydraulic subsystem which powers the aerodynamic control surfaces. Heat is removed by ram air discharging through an air/liquid heat exchanger. Heat is transmitted into the hydraulic subsystem by two means: (1) heat conducted in through the structure during entry and (2) heat generated by the hydraulic pumps when the aerodynamic control surfaces are active.

Heat conducted into the subsystem during entry is stored by heat sinking until the cruise engines are operational. Since the control surface actuators are primarily used during cruise, most of the heat generated in the subsystem is during the cruise phase of the mission. Ram air cooling therefore provides a simple reliable means of heat removal from the hydraulic subsystem.

3.4.3.2 Booster - The booster ECS must provide the atmosphere supply, and cabin and equipment temperature control. The ECS consists of four subsystems: the oxygen supply, the heat transport circuit, the air cycle, and the hydraulic cooling subsystems. These subsystems, with the exception of the hydraulic cooling subsystem, are shown schematically in Figure 3-98. The operation of each subsystem is summarized in the succeeding paragraphs.

a. Oxygen Supply - The oxygen supply subsystem provides an emergency supply of oxygen. In normal flight, the cabin will be pressurized to the equivalent of an 8000 ft. altitude and additional oxygen will not be necessary. If the cabin pressure is lost, then the oxygen supply will provide oxygen until the vehicle is brought down to an altitude where cabin pressurization is not necessary.

b. The Heat-Transport Circuit - The system uses redundant coolant loops, and dual passage coldplates for the thermal control of electronic equipment. The secondary loop is used if a failure occurs in the primary loop. Redundant coolant pumps in each loop circulate the heat transfer coolant. Waste heat is rejected by an air cycle refrigeration package during subsonic cruise flight or during ferry flights. Prior to launch the air cycle machine is powered by a ground supply of high pressure air. During the boost phases of flight, heat dissipated by the electrical equipment is absorbed by equipment, coolant fluid, and circuit component temperature increases. Subsequent to boost the air cycle is powered with bleed air from the jet engine compressor.

c. Air Cycle - The air cycle subsystem serves a dual function, providing cabin air conditioning and pressurization, and providing cooling for the heat transport circuit. Jet engine compressor bleed air is cooled by heat exchange with ram air, is compressed, again is cooled by ram air and then is further cooled by expansion in a turbine that drives the compressor.

BOOSTER ECS SCHEMATIC

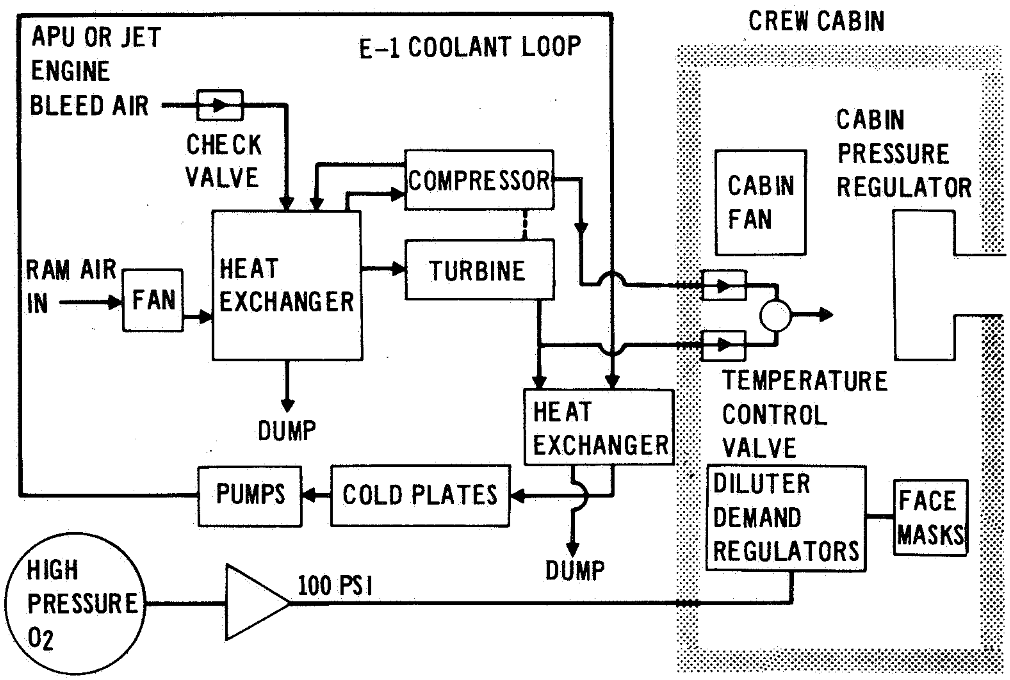

FIGURE 3-98

The cold air removes heat from the coolant circuit and then is mixed with hot air from the compressor to control the cabin temperature.

d. Hydraulic Cooling - This subsystem prevents overheating of the fluid in the hydraulic subsystem which powers the aerodynamic control surfaces. Heat is removed by ram air discharging through an air/liquid heat exchanger.

3.4.4 Integrated Avionics - The emphasis of the Space Shuttle program is to achieve a high level of operational economy. This requirement, in conjunction with vehicle operation in the booster, spacecraft and aircraft flight regimes requires a new look at the design and implementation of the Avionics System. The new approach is called an "Integrated Avionics System" and it considers all known functional requirements of the mission during initial vehicle system design.

The basic rationale for the use of Integrated Avionics is derived from the measures required to achieve economy of operation. These measures are a self contained, crew controlled, prelaunch checkout capability, rapid turn around/reuse capability and a higher degree of mission success. Avionic capabilities must include self checkout, block and functional redundancy, and maintenance to a Line Replaceable Unit (LRU). These capabilities produce a large amount of system status data. This data, in conjunction with the system complexity due to the vehicle multiregime operation, require an advanced Integrated Avionics capability. To ensure compatibility with manned control, the Integrated Avionics system will provide a highly efficient data management and display/control capability. It will relieve the crew of excessive workload by automatically performing time critical functions and by providing priority sorting and data compression of that information needed by the crew.

The general avionic functions are:

- Vehicle Self Test and Warning
- Data Processing and Transfer
- Crew Command and Integrated Displays
- Target Tracking
- Autonomous Navigation and Flight Control
- Satellite Communications
- Supporting Energy Conditioning

More specific functions by mission phase are described in Figure 3-99.

AVIONICS–MISSION FUNCTIONS

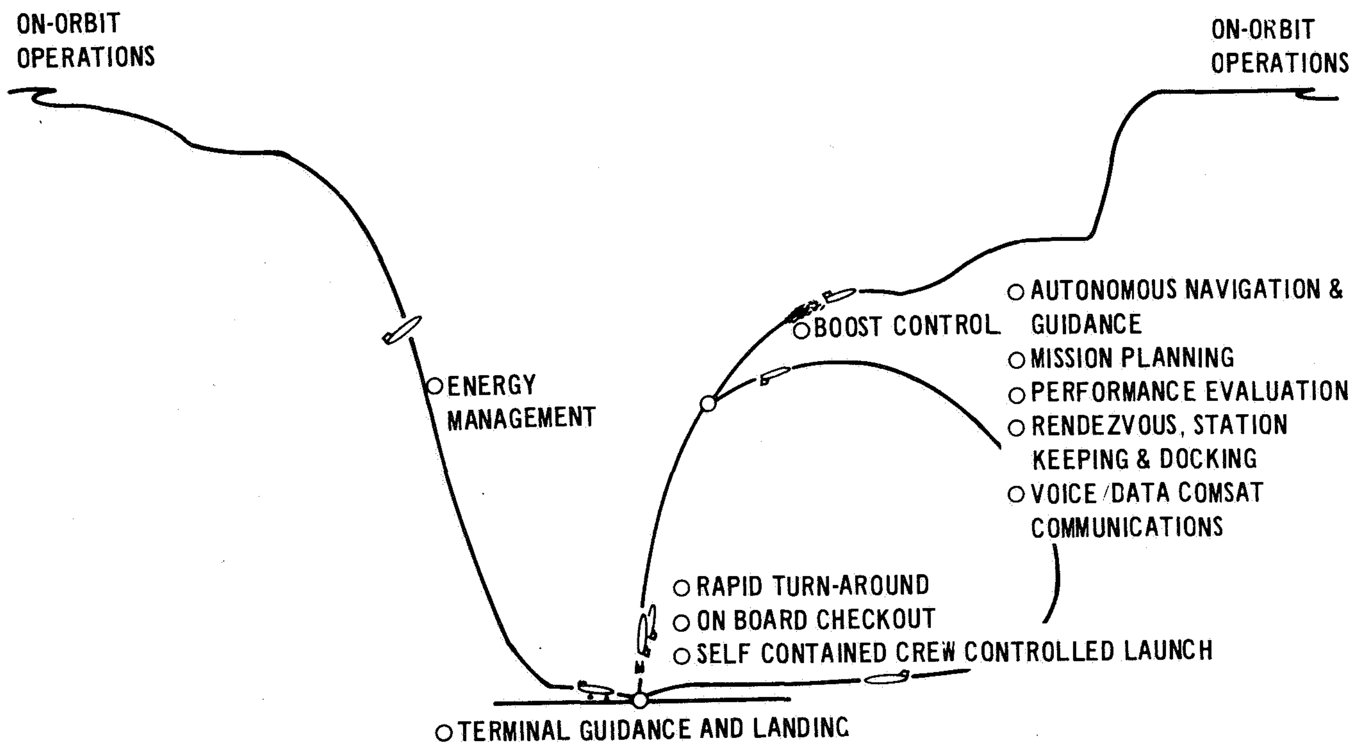

FIGURE 3-99

3.4.4.1 System Definition - The elements of the Integrated Avionics system are shown in Figure 3-100. Equipment and configuration selection was made on the basis of: (1) an estimate of the 1972 technology status and (2) use of concepts which provide small development risks.

Inertial sensors are used as the prime source of navigation data through all active mission phases. Choice of inertial systems in both the booster and orbiter were dictated by the ascent guidance, entry to a pre-determined landing site and automatic landing requirements. Star trackers and horizon sensors provide autonomous on-orbit attitude and navigational updates. The multi-mode rendezvous radar provides for rendezvous with either cooperative or non-cooperative vehicles. A dedicated navigation computer supplies the unique requirements of individual system sensors while permitting the central software programming tasks to be maintained at a manageable complexity level. This keeps sensor unique computational requirements from impacting the central computational requirements.

The UHF communication link is utilized for EVA, inter-vehicle voice or data, and airport communication during the approach and landing phase. The Comsat-link provides nearly continuous communication capability between any ground station and the orbiter during the orbital phase of flight.

The display concept utilizing cathode ray tubes for multimode data presentation permits crew decisions on important tasks while relieving them of the need to monitor a large number of displays and meters.

A common, multiplexed data bus was selected to provide standardized digital interfaces, and to reduce the complexity and weight of itnerconnecting systems. The intermix of computers consists of a central data processor to perform mission oriented functions, and peripheral dedicated computers for sensor functions, navigation, flight control, and propulsion computations. This arrangement was chosen on the basis of commonality of requirements while maintaining equipment and software at manageable complexity levels. Thus, sensor oriented computational requirements, both hardware and software, do not impact the central computer.

Onboard checkout minimizes ground support and expedites maintenance and reuse. Decentralized Built-In Test (BIT) was selected over a separate centralized test system to minimize interface complexity and provide subsystem functional autonomy. BIT provides self-test at all maintenance levels and permits identification of failures to the line replaceable units. Selective computer controlled access permits transmission of data pertinent to a particular mission phase, whether it be for flight, caution and warning, or ground base checkout.

BASELINE ORBITER INTEGRATED AVIONICS SYSTEM

COMMUNICATIONS
- SHF* (2) & UHF (2) TRANSCEIVERS
- PROCESSOR (3)
- INTERCOM & HEADSETS (2)
- OMNI ANTENNAS (4)
- *SHF DISH ANTENNA (1)

GUIDANCE AND NAVIGATION
- INERTIAL MEASUREMENT (3)
- NAV COMPUTER (3)
- *INTEGRATED OPTICAL & IR (2)
- *RENDEZVOUS RADAR (2)
- *DOCKING SENSORS (3)

LANDING & NAVIGATION AIDS
- VORTAC TRANSCEIVER (2)
- RADAR ALTIMETERS (3)
- AIR DATA SENSORS (3)
- ADVANCED ILS (3)

ELECTRICAL
- *FUEL CELL (2 OUT OF 4)
- *REACTANT SUPPLY (25%)
- BATTERIES (2)
- INVERTERS (4)

CENTRAL MANAGEMENT
- CENTRAL COMPUTER (3)
- CREW

DISPLAY & CONTROL
- MODE CONTROL PANEL (2)
- HAND CONTROLLERS (2)
- MULTI-PURPOSE CRT DISPLAYS (6)
- HEAD-UP DISPLAY (2)
- *PRINTER (1)

CHECKOUT & MONITORING
- PROPULSION PROCESSOR (3)
- INSTRUMENTATION PROCESSOR (3)
- INSTRUMENTATION SENSORS
- REMOTE MULTIPLEXERS
- FLIGHT RECORDER (2)
- *REMOTE TV CAMERAS

FLIGHT CONTROL
- PROCESSOR (4)
- POWER SERVO AMPLIFIERS (4 PER FUNCTION)
- RATE GYRO (BACK-UP – 1)

*DENOTES SYSTEMS NOT USED ON BOOSTER

FIGURE 3-100

4.0 COST ANALYSIS

Cost analysis involves the investigation of vehicle and program definition, the translation of these definitions into the program cost estimates, and the analysis of cost sensitivities to various vehicle and program alternates. This section of the report presents the cost methodology which forms the basis for the derived costs, the ground rules to which the costs are estimated, the estimated costs, and the associated cost sensitivities.

4.1 Cost Methodology - The cost model developed during Tasks 1 through 6 of the basic OCPDM study was used as the basis for estimating the cost of the vehicles defined in the follow-on study effort. A complete discussion of the Cost Estimating Relationships (CER's) that were developed for this cost model is contained in Reference 4. The CER's were directly applicable to the follow-on study with the exception of a few slight adjustments. The vehicles and programs defined during the follow-on study also contained subsystems or functions for which there were no CER's in the cost model. These items required separate calculations since specific CER's were not defined for these items. The necessary additions, modifications, or deletions are discussed in the following paragraphs.

In accordance with the study ground rules the CER's for the zero stages of Concept "S" vehicles were provided by the NASA.

4.1.1 First Unit Cost CER's - The necessary additions or adjustments to the first unit cost CER's are outlined below:

a. Thermal Protection System, Radiative - The CER as written in the basic OCPDM cost model is in error since it does not have an exponent on the wetted area (SWTPR) parameter and therefore, does not account for the size (wetted area) effect on the cost. Subsequently, the CER results obtained in the follow-on effort have been reduced to account for this size effect.

b. Landing Gear - For the Concept "S" vehicle this CER output was increased since the landing gear is constructed with composite materials and the current CER has no material complexity factor.

c. ECS - The ECS cost was increased slightly to provide additional equipment costs for functions performed that were not a part of the Gemini type system from which the CER was derived.

d. Entry Attitude Control System - This is a gaseous O_2/H_2 propellant system and the class 4 regenerative cooled, pump fed, LOX/LH_2 system CER was used to estimate the engine cost.

e. Airbreathing jet engines - The cost of the jet engines is based on Rand Report RM-4670-PR, dated November 1965.

4.1.2 RDT&E CER's - The necessary additions, adjustments, and deletions to the RDT&E CER's are outlined below:

a. Structural testing - The cost was reduced by 1/3 because of the reduction in ground test hardware.

b. ECS - The ECS cost was increased slightly to provide additional development costs for functions performed that were not a part of the Gemini type system from which the CER was derived.

c. Entry Attitude Control System - The class 4 regenerative cooled, pump fed, LOX/LH_2 CER was used to estimate the engine cost for this subsystem.

d. Airbreathing Jet Engines - The airbreathing jet engines were considered as off-the-shelf items with 25% of the original development cost as estimated by Rand Report RM-4670-PR charged for any possible required modifications or changes.

e. Aerospace Ground Equipment (AGE) - The output of these CER's was slightly reduced to reflect the vast amount of onboard checkout equipment.

f. Launch Facilities - The facilities costs are based on modification of existing launch facilities.

g. Trainers and Simulators, Mockups, and System Engineering - The costs in the model are calculated as a percentage of other cost elements. Since these cost elements are now considerably higher than the base from which the percentage factors were derived, the cost model output of these 3 functions was reduced slightly.

h. Horizontal flight testing, Vertical flight testing, and Refurbishment - These costs required separate calculations since the cost model does not have CER's for estimating these elements.

4.1.3 Operational Phase CER's - The operational CER's were developed from the data presented in Reference 4 to accommodate a range of operational philosophies, payload sizes and total program sizes. Three operational philosophies were considered during the study; namely, the business as usual (BAU) approach of the basic study, the ILRV approach of quick turnaround, and an intermediate approach which is less conservative than the business as usual approach.

Recent shuttle studies involving several different approaches to an ILRV system required the development of an operational philosophy and an operational cost model more representative of the ILRV system than the "Business As Usual" philosphy and model presently structured in the basic OCPDM study results. An ILRV system is characterized by an integrated launch-recovery complex, limited scheduled maintenance performed in a short time, and little of the present pre-launch activities, other than pad erection and countdown. These characteristics eliminate transportation, reduce flow time, reduce inventory requirements, and reduce the manpower levels required to sustain a program. All of these contribute to reduced operating costs which was one of the purposes of the ILRV shuttle studies.

An integrated launch-recovery-recertification complex has many advantages. It provides a dedicated launch and recovery site, free from the compromises necessary when launch is from ETR or WTR and recovery is at existing civilian or military airfields. Existing sites demand that the needs of all users be given equal consideration. In the high traffic programs envisioned in the ILRV studies such a situation is hardly tolerable. The dedicated site, free from any other launch or aircraft traffic, offers the potential for the least costly operating mode. Inclusion of the recertification facility at this complex is a logical extension of the concept. There is little reason to transport a space vehicle to another location for recertification when it could be done right at the recovery site.

Recertification is a much less elaborate activity in the ILRV approach. The shuttle vehicles are designed for long life and easy maintainability. The subsystems have a much longer useful life, as compared to present systems, due to high reliability, longer design life, and much less non-flight operation (repetitive testing).

The detailed recertification model utilized in this study is a modification of the model developed in the basic OCPDM study. The ILRV recertification is based on data presented in Reference 5. This reference study defined a scheduled maintenance cycle similar to the type followed for commercial and military aircraft. The operating life of the various subsystems was estimated in flights, based on the expected hours of operation per flight. The thermal protection system life was estimated from the expected thermal environment of the nominal mission profile. Some components had nearly unlimited life while others such as leading edges and nose caps had a five flight life. The scheduled maintenance cycle replaced portions of the TPS as the expected life was reached. The basic airframe, including landing gear, was assumed to have unlimited life.

This scheduled maintenance approach requires that an additional amount of effort be allotted to unscheduled maintenance. Unscheduled maintenance in this study is defined in man-hours only, the materials for this activity are assumed drawn from the spares stock.

There is a limited amount of testing during the recertification. For the ILRV approach, testing is limited to continuity validations only. Testing over the operating range is not performed. If a component is due for replacement, it is removed and a fully tested replacement installed, the continuity checked to be certain the replacement is correctly installed, and the job sealed. There is no full system test until the prelaunch countdown which is the only time before flight that all systems are checked.

This scheduled maintenance approach does not reduce the amount of inspection performed. The burden on quality assurance is greater due to the elimination of all possible repetitive testing. The flow time is keyed to the scheduled and unscheduled maintenance, but the manpower levels reflect the presence of quality assurance throughout the recertification.

Launch operations for the ILRV philosophy attempt to reduce costs to a minimum without loss of success probability in jeopordizing the safety of a flight crew. The "business as usual" activities were reviewed individually. Each was reduced to some minimum which, in the judgement of the analysis, was the least effort permissible to achieve a successful mission. Pad testing was eliminated since the ILRV approach relies on the countdown to detect anomolies. The two major reductions were in industrial area activities and countdown. This is an operational program which assumes a fixed vehicle configuration, and uses onboard checkout in the vehicles. In an operational program, with the vehicles operating at an integrated complex, the vehicle is delivered directly to the pad, pausing only to load cargo and some expendables. Onboard checkout greatly speeds the checkout sequence by verifying that all systems are operating within tolerance. The ILRV approach does not consider the exact value of each measured parameter, or compare that value to previous test data, as is done in the "business as usual" approach. Greater reliance is placed on the integrity of the subsystems, and they are given a go-no-go type of test only. Propellant costs can not be reduced; thus, pad assembly and propellants are the two major costs in the ILRV launch operations.

The costs of the other activities associated with operations are also reduced in the ILRV approach. With fewer manhours involved in launch operations, the manhours in launch area support are greatly reduced. Training costs can be reduced because this is a logistic shuttle operation with little or no variation in mission profile. Consequently, flight crew need only refresher courses rather than extensive retraining between flights. AGE and facility maintenance are significantly reduced by elimination of much of the "business as usual" AGE and by less complex launch facilities. Due to the nature of the program, sustaining engineering and technical support can be reduced to 60% of the "business as usual" value. The longer life, higher reliability components permit a reduction in the quantity and cost of sustaining spares.

4.1.4 Zero Stages - The CER's for the zero stages were provided by the NASA. These were programmed into a small cost model providing all costs, such as RDT&E, investment and operational costs, for the solid versus liquid and expendable versus reusable approaches to the zero stages. These costs were then added to the core vehicle costs for Concept "S" to provide the appropriate total program costs.

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4.2 Cost Ground Rules - The following ground rules, assumptions, and program definitions are reflected in the estimated costs for the follow-on study effort.

a. All costs are in 1969 dollars and are based on the labors rates as established by the basic OCPDM study.

b. The primary development costs of common subsystems are charged to the orbiter with small additional costs for these subsystems charged to the booster for modifications and peculiarities.

c. Ground test hardware consists of approximately 1.2 equivalent cost units (i.e., 1.2 times first unit cost).

d. The flight test hardware included in the RDT&E phase consists of 2 complete production hardware vehicles.

e. The flight test vehicles procured in RDT&E phase are completely refurbished and used to help meet the operational phase inventory requirements.

f. The landing assist jet engines are considered off-the-shelf items with 25 percent of the estimated original development cost charged for modifications.

g. Three sets of AGE are included in the estimated costs.

h. The horizontal or subsonic flight test program consists of 140 flights on the orbiter and 100 flights on the booster.

i. The vertical (suborbital and orbital) flight test program consists of 9 flights on the orbiter and 6 flights on the booster; 3 of which are combined launches.

j. The probability of mission success for the ILRV, intermediate, and business-as-usual approaches are .985, .975, .975 respectively. The probability of safe recovery is .995 for all approaches.

k. No design life limitations were assumed for the core vehicles. Reusable stage zero units were assumed to have a 20 flight life.

l. Program life assumed was 10 years. At the end of this time, all remaining vehicles are in flight-ready condition.

m. The payload costs are excluded.

n. The contingency weight has been excluded from all cost calculations that are weight sensitive.

o. Fee is included as a separate element at 10 percent.

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4.3 <u>Cost Element Structure</u> - The Cost Element Structure (CES) developed for the basic study has been modified slightly to meet the requirements of the vehicles and programs as defined by this follow-on effort. Generally, these modifications include the deletion of subsystems or functions not included in the follow-on vehicles or programs or the addition of subsystems or functions not previously provided for by the basic CES. Definitions of the various elements are the same as defined by the basic CES. Added elements include the landing and cruise jet engines, horizontal flight testing and refurbishment. These added elements are described as follows:

a. Landing and Cruise Jet Engines - Includes the cost of the engines and the necessary installation items for fuel and controls.

b. Horizontal Flight Testing - Includes in-plant and remote site costs for the horizontal take-off and landing subsonic test program.

c. Refurbishment - Includes refurbishment costs for repairs and modification resulting from the flight test program to maintain and return the vehicle to an operational status.

The basic CES as developed for the entry vehicle module with above noted modifications is applied to both the orbiter and boost vehicles. The zero stage element essentially replaces the launch vehicle element. Figures 4-1 through 4-4 present the CES as defined for this follow-on effort.

TOTAL PROGRAM COST ELEMENT STRUCTURE

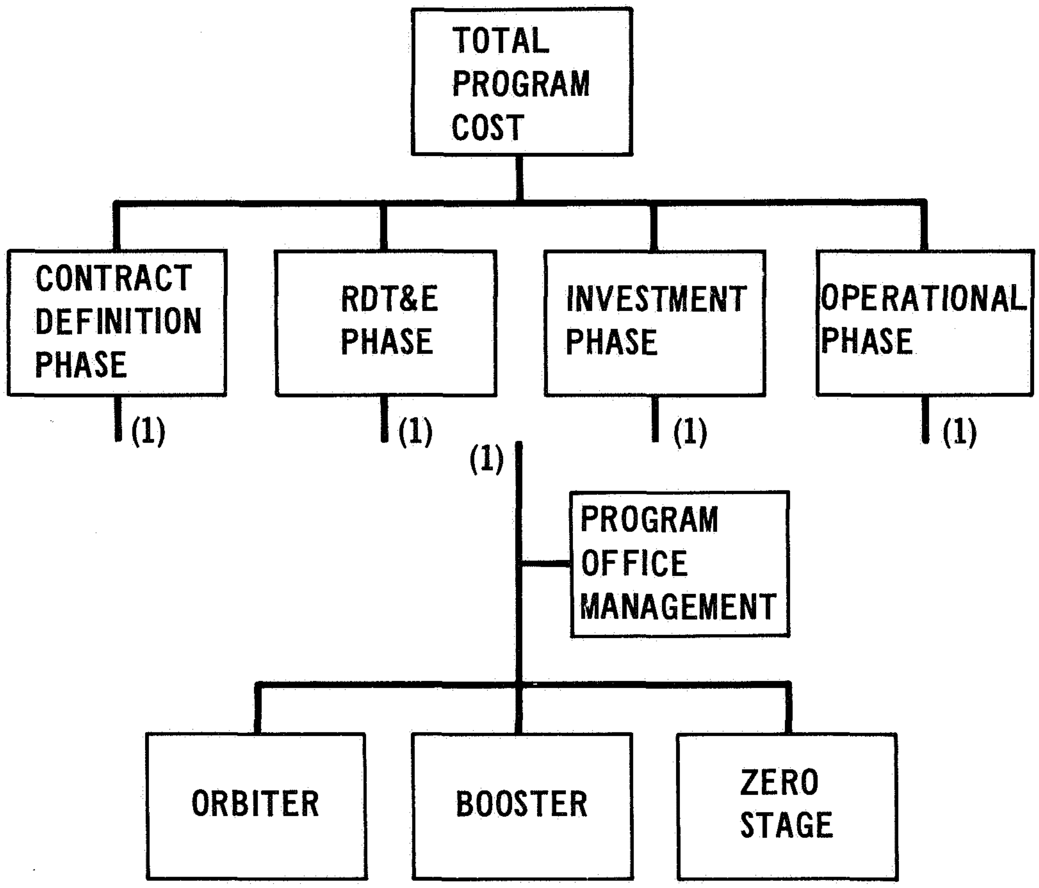

FIGURE 4-1

RDT&E COST ELEMENT STRUCTURE

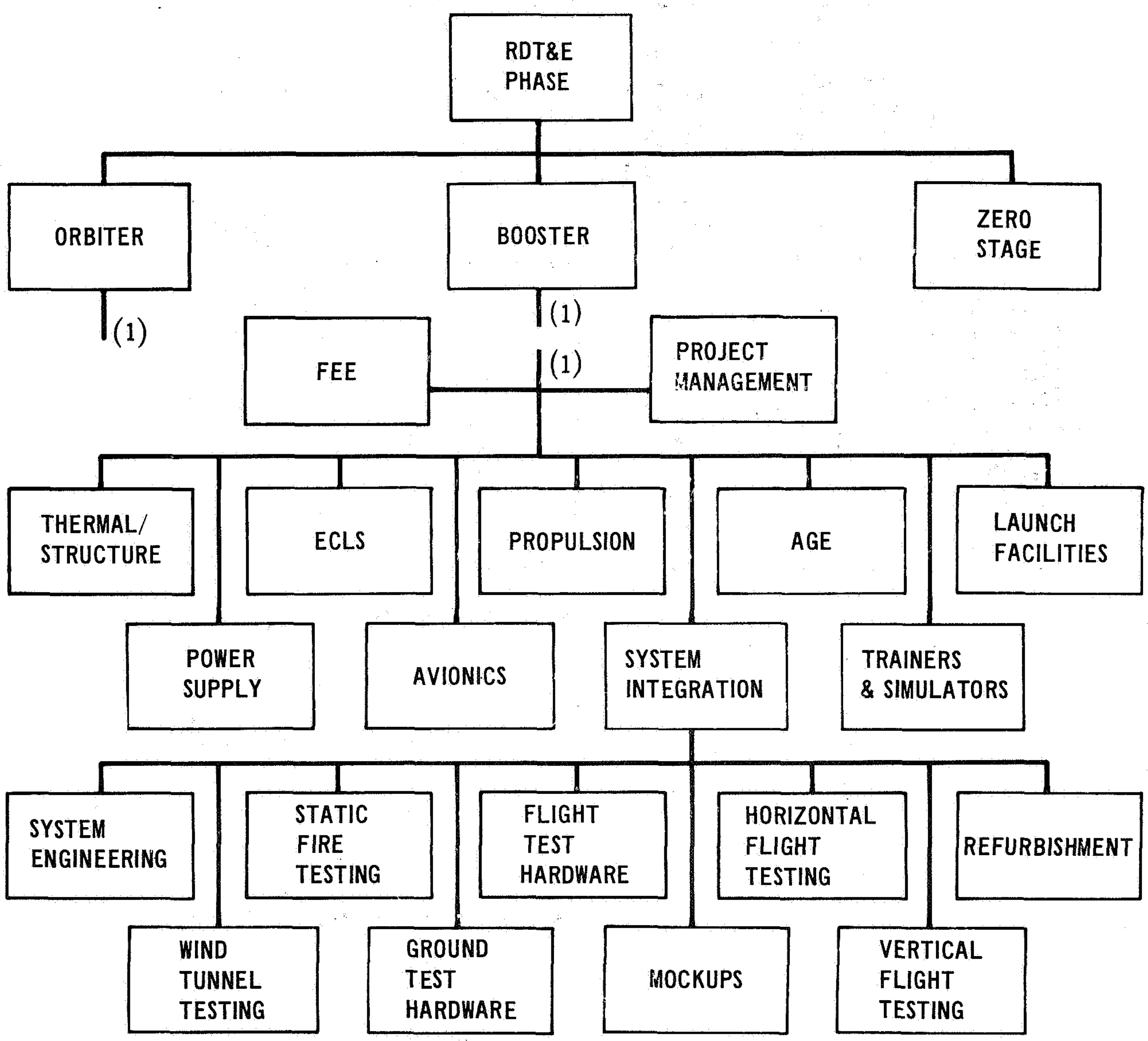

FIGURE 4-2

INVESTMENT PHASE COST ELEMENT STRUCTURE

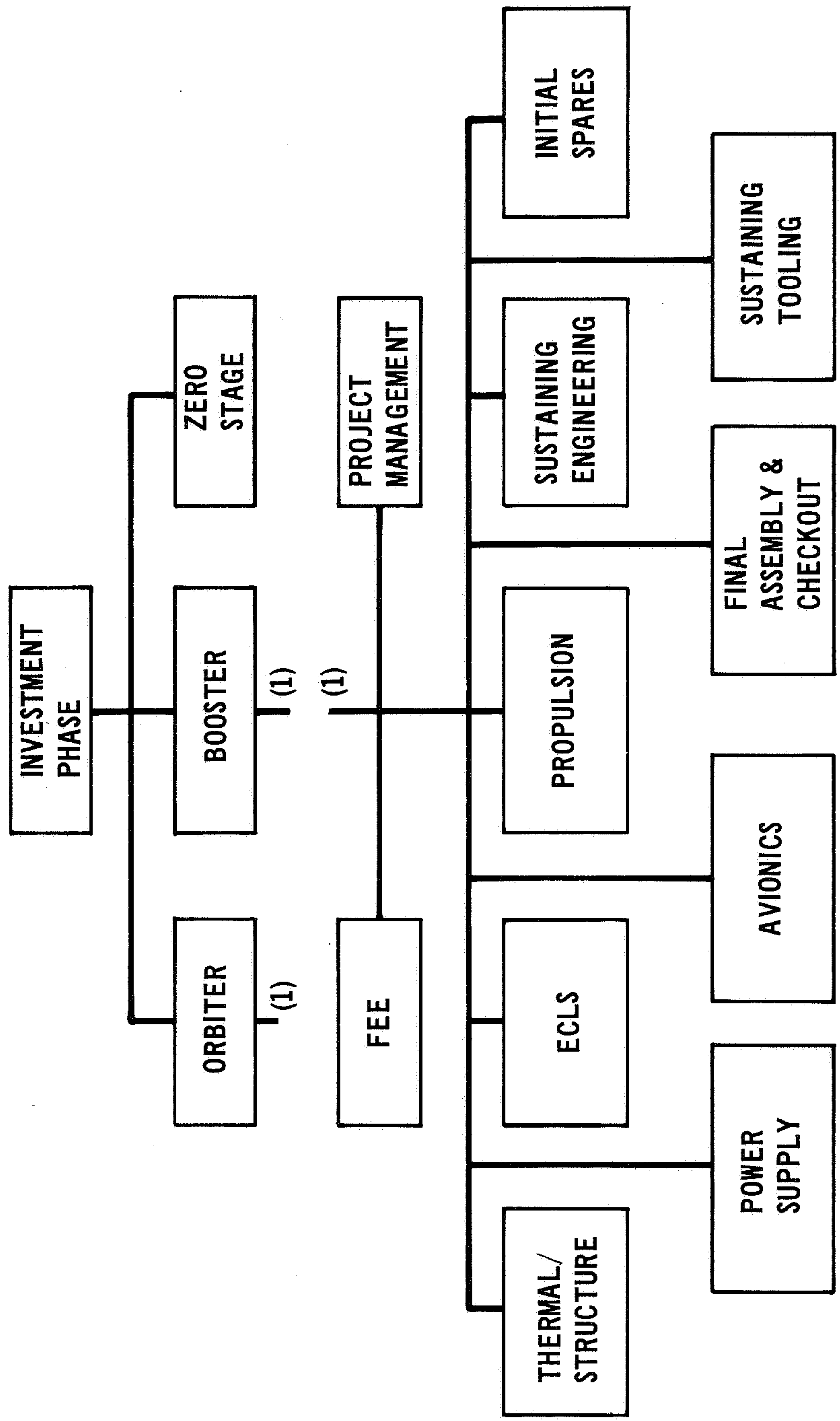

FIGURE 4-3

OPERATIONAL PHASE COST ELEMENT STRUCTURE

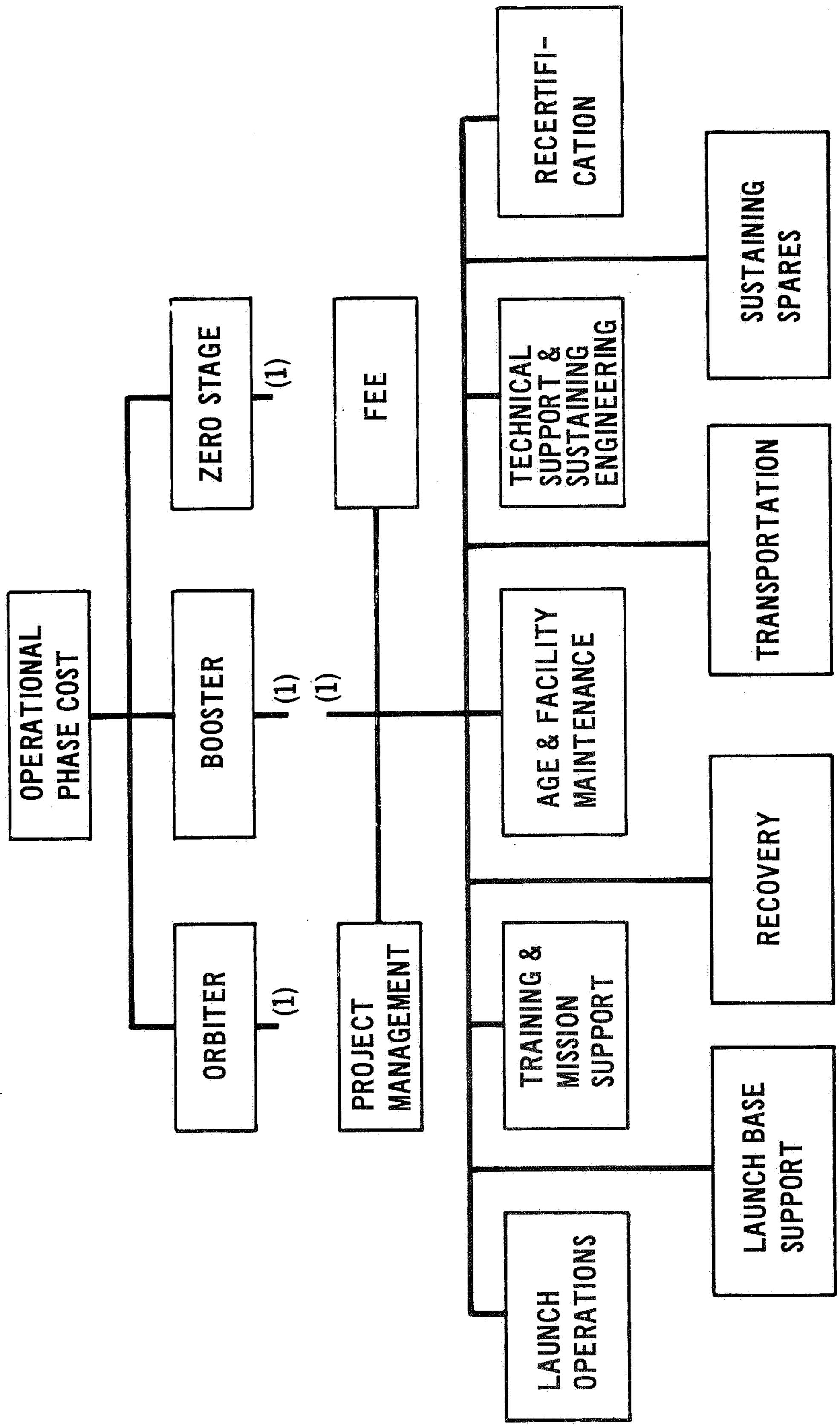

FIGURE 4-4

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4.4 System Analysis - The detailed cost estimates generated using the tools discussed previously are presented in Appendix A. The results have been plotted here in this section of the report to graphically present the data for trend analysis and easy comparison. In general, the trends indicated in this study agree with those of the basic OCPDM study as documented in Reference 4. This section of the report presents concept "S" for the constant length and two constant ΔV cases, Concept "L", Concept "M" and then some comparisons of all three concepts.

4.4.1 Concept "S" - The study considered three variations of the Concept "S", one with the length fixed at 165 feet, and two with the orbiter stage ΔV fixed at either 18,790 FPS or 20,890 FPS.

Figure 4-5 presents the trends of total cost versus payload size for the constant length configuration. The differences shown in operating philosophy are for four different traffic rates covering the range from 250,000 to 2.5 million pounds per year delivered. There appears to be a cost minimum at a payload size near 50,000 pounds. There were insufficient cases run to establish this cost minimum location, but the results agree with trends indicated in the basic OCPDM study, Task 6. As expected, the ILRV operational philosophy is the least costly being approximately one quarter of the business-as-usual (BAU) philosophy shown and used in the basic OCPDM study. As the payload size increases, the amount of traffic to deliver a given amount of payload reduces producing the expected downward trend of the cost curve with increasing payload size. Payloads in excess of 50,000 pounds were not considered. The basic OCPDM study indicated that payloads on the order of 75,000 pounds are the least-cost size for very high traffic programs.

Figure 4-6 and 4-7 are cross plots of the data given in Figure 4-5 showing the total program cost trends as a function of total payload delivered and flights per year. Payload size has little effect on the total costs when flights per year are considered which is as expected for this concept.

Figures 4-8, 4-9 and 4-10 show various trends of the recurring costs. For this study, recurring costs are defined as the sum of the investment and operational costs. The number of flights used is the number of attempted launches. As expected, recurring costs increase with payload size; however, in the ILRV operational philosophy they are nearly constant. In fact, there is a significant amount of scatter to the ILRV philosophy data indicating the model used may be overly sensitive to certain parameters.

TOTAL COST VS. PAYLOAD SIZE

Constant Length Concept S With Expendable Solid Zero Stage

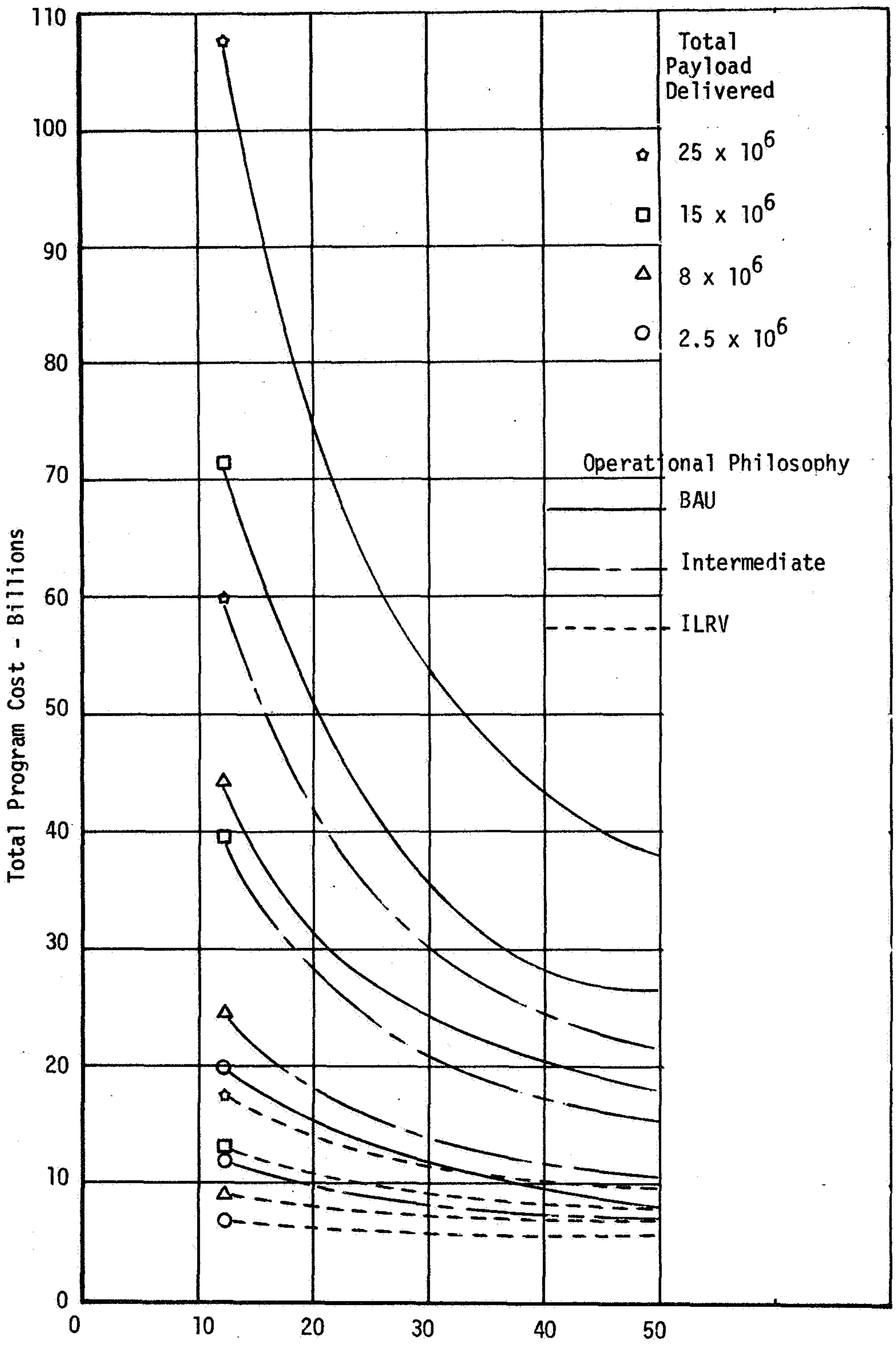


FIGURE 4-5

TOTAL PROGRAM COST VS. TOTAL CARGO WEIGHT

Constant Length Concept S With Expendable Solid Zero Stage

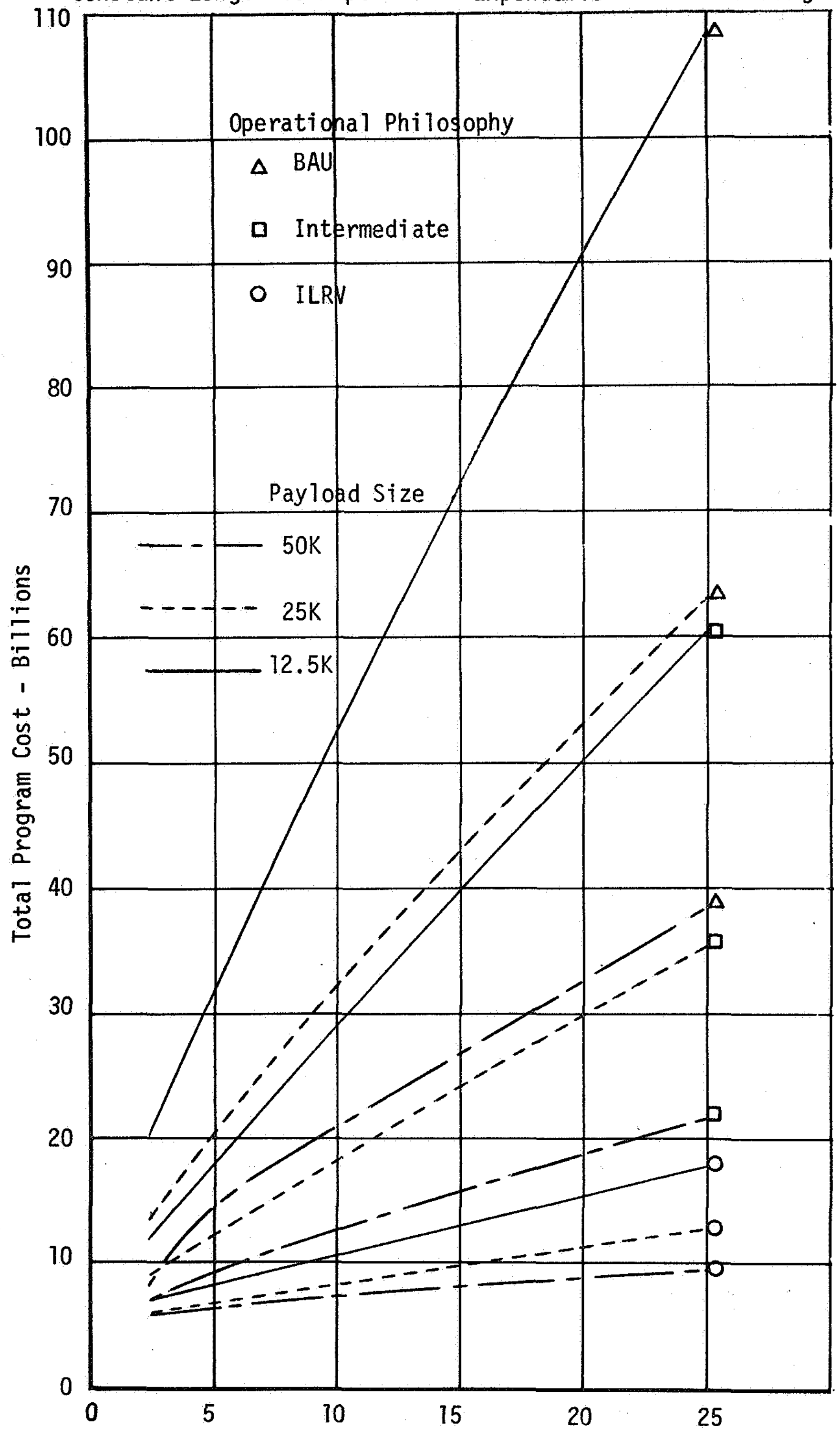


FIGURE 4-6

TOTAL PROGRAM COST VS. NUMBER OF FLIGHTS

Constant Length Concept S With Expendable Solid Zero Stage

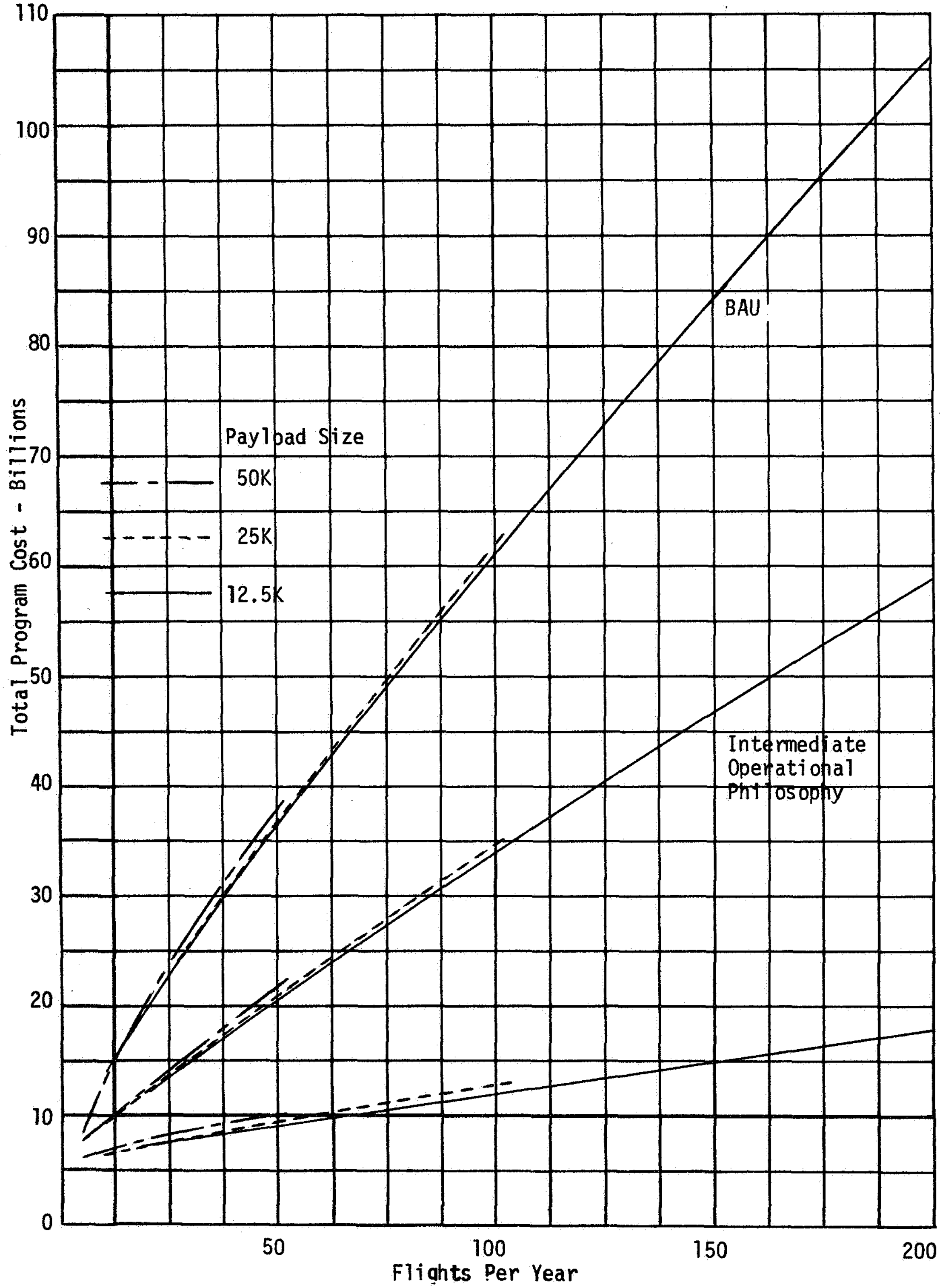


FIGURE 4-7

RECURRING COST PER FLIGHT VS. PAYLOAD SIZE

Constant Length Concept S With Expendable Solid Zero Stage

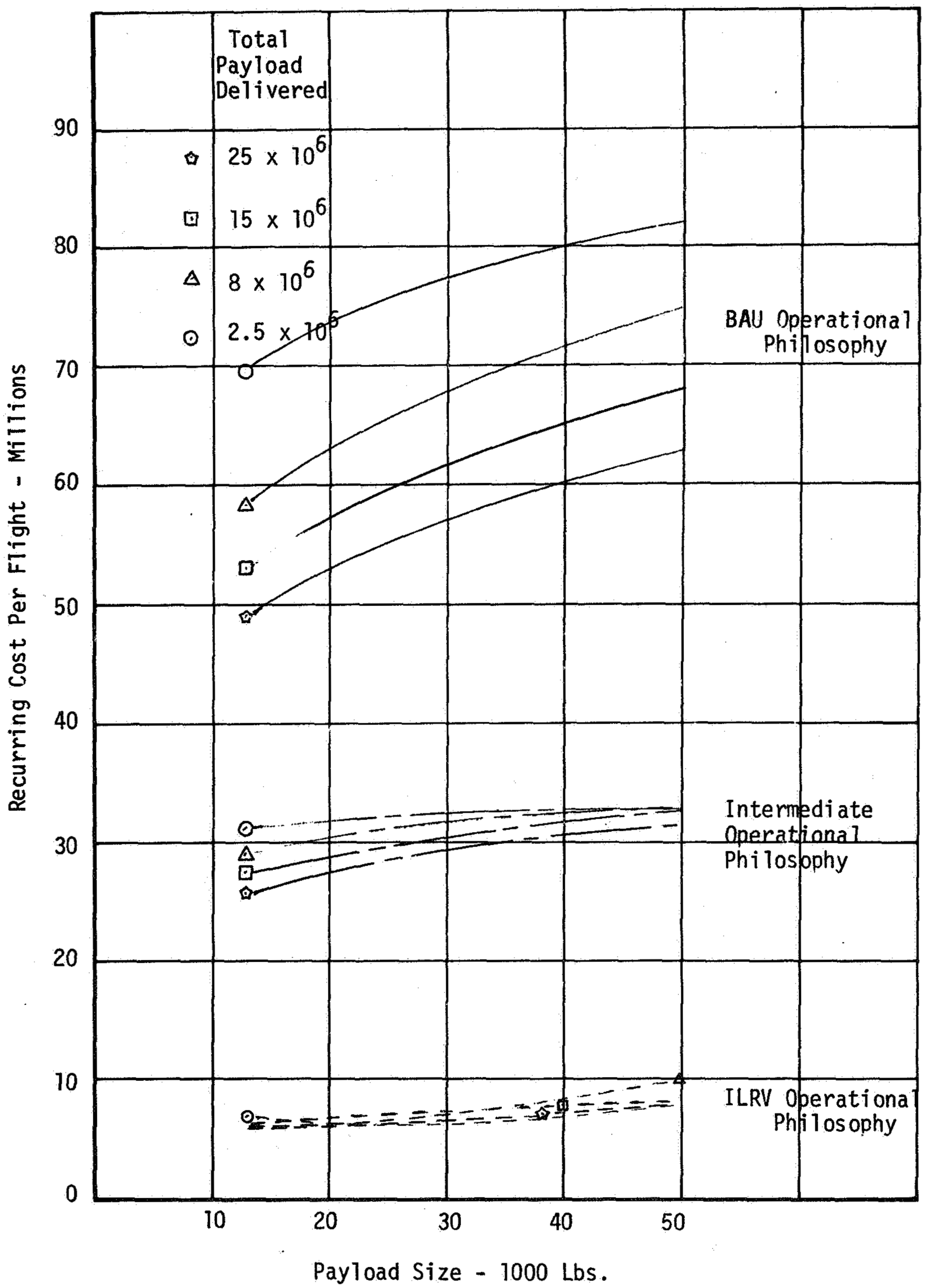


FIGURE 4-8

RECURRING COST PER FLIGHT VS. FLIGHTS PER YEAR

Constant Length Concept S With Expendable Solid Zero Stage

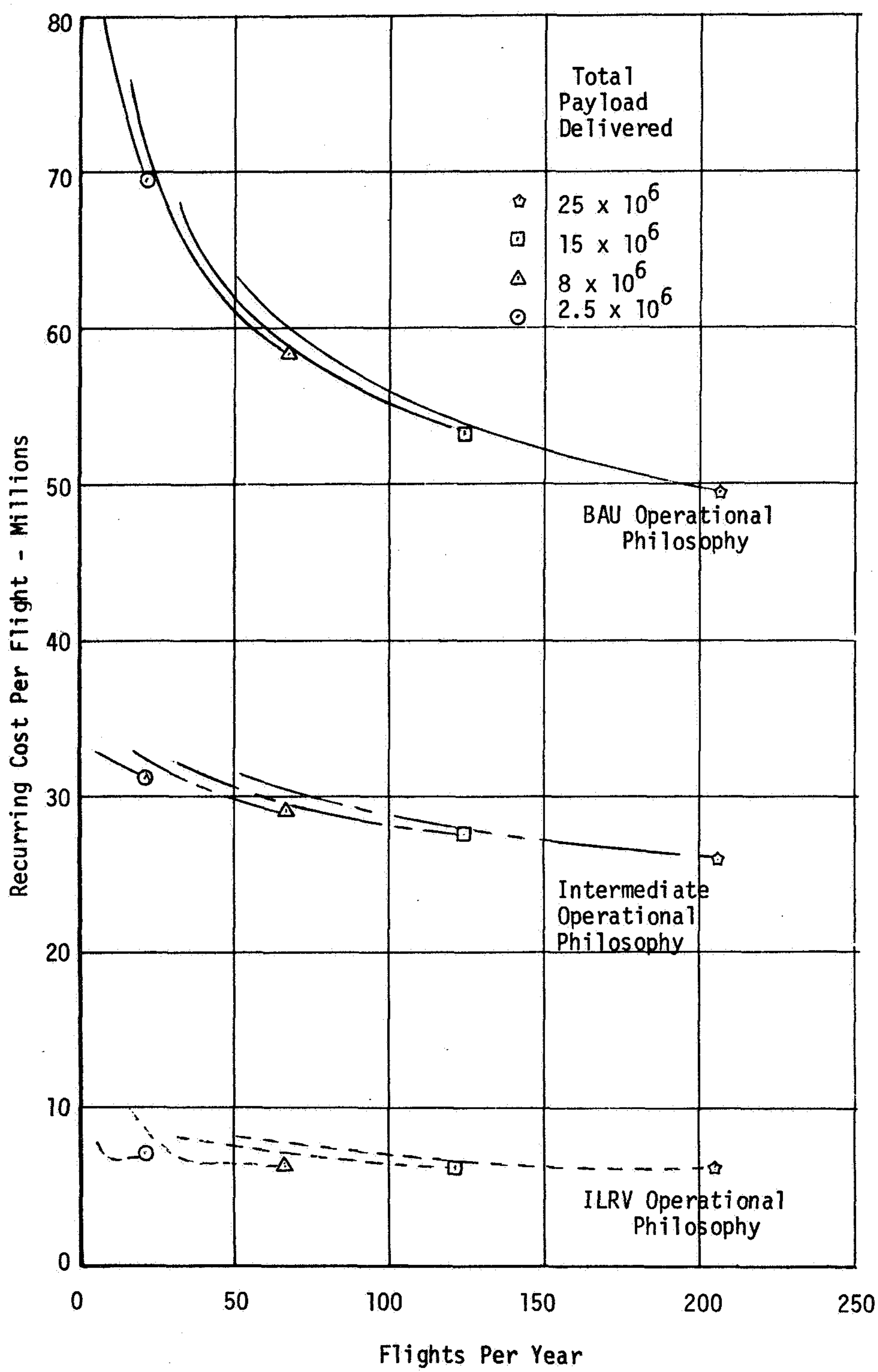


FIGURE 4-9

RECURRING COST VS. PAYLOAD SIZE

Constant Length Concept S With Expendable Solid Zero Stage

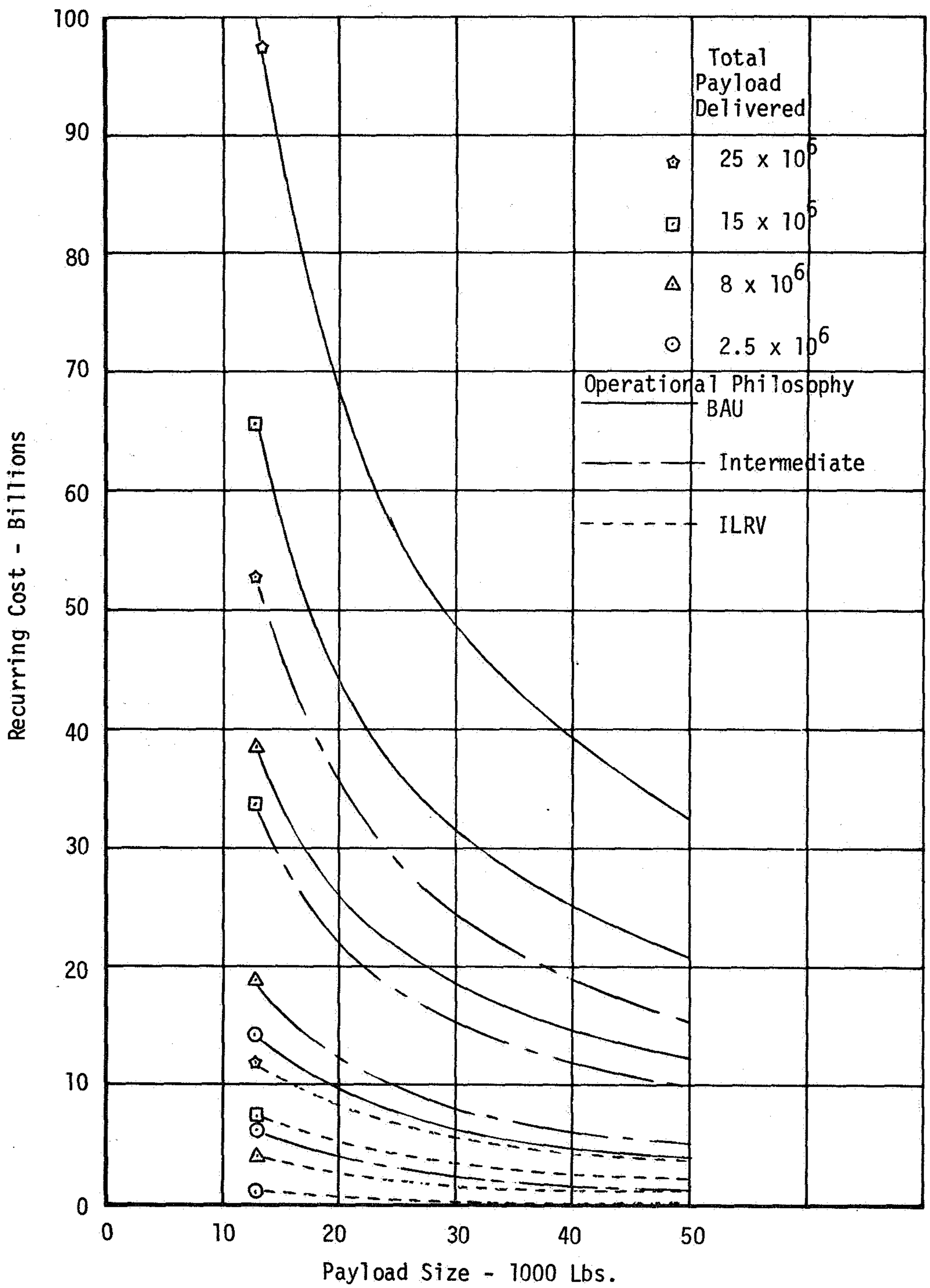


FIGURE 4-10

Figures 4-11, 4-12, and 4-13 present a breakdown of the operational costs for the 50,000 pound payload size at the 8 million pound traffic rate indicating that the two major cost centers are launch operations and recertification. The cost of propellants are included in the launch operations costs as noted in the data presented in the appendix. For all operational philosophies, the recertification costs are very significant.

Figure 4-14 presents the total program cost trends for the four zero stages considered. The zero stage cost model used in this study was supplied by the NASA. The development costs of the solid stages are considered sunk costs and were not charged to the program. The costs of solid propellant is included in the investment and recertification cost whereas the costs of liquid propellants are included in the launch operations costs. For this reason, the recurring costs are more meaningful for comparisons of the four approaches. The recurring costs as a function of payload size and flights per year are shown in Figure 4-15, and 4-16. The recurring costs per flight are shown in Figure 4-17.

It should be noted that only the 50,000 pound payload configuration for Concept "S" represents a near optimum design point. This fact should be taken into consideration when comparing costs with the other payload sizes analyzed.

The constant ΔV Concept "S" considered two ΔV values, namely 18,790 and 20,890 FPS. The total program cost trends and the recurring cost trends for the ΔV = 18,790 FPS case are shown in Figures 4-18 and 4-19 respectively. The trends are similar to those for the constant length case discussed previously. The recurring cost per flight is shown as a function of the flights per year in Figure 4-20.

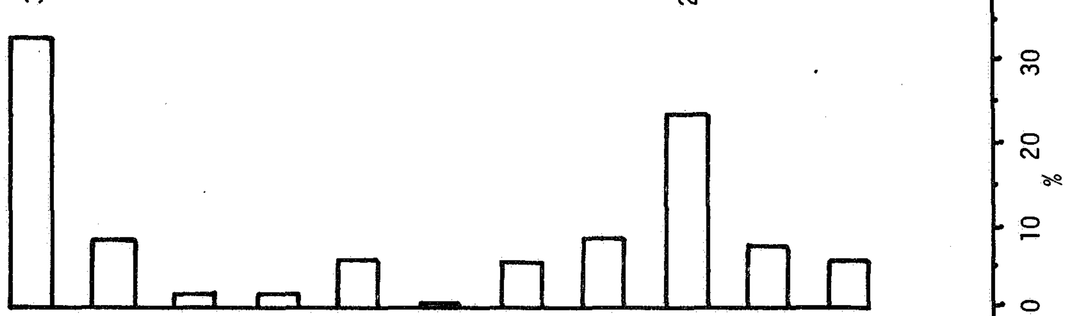
The zero stage cost trends for the constant ΔV = 18,790 FPS case are shown in Figures 4-21, 4-22, 4-23, and 4-24. The recurring costs per flight as a function of payload size appears to have an inflection point at some traffic rate between the 8 million and 15 million pounds delivered. Below this value there is some payload size which has the lowest cost per flight, above this value the curve has no bucket within the range considered.

The cost trend curves for the constant ΔV = 20,890 FPS Concept "S" case are shown in Figures 4-25 through 4-30. They are similar in shape and trend conclusions to those shown previously.

OPERATIONAL COST SUMMARY MILLIONS OF 1969 DOLLARS

Constant Length Concept S 8M Total Payload ILRV Philosophy

Payload Size = 50,000 Lbs.	Orbiter	Orbiter %	Booster	Booster %
Launch Operations	$92.6	32.7%	$81.7	30.0
Launch Area Support	23.3	8.2	23.8	8.7
Training & Mission Support	4.0	1.4	4.0	1.5
AGE & Facility Maintenance	4.1	1.4	4.5	1.7
Recovery	16.4	5.8	16.4	6.0
Transportation	0.3	0.1	0.3	0.1
Tech. Support & Sustaining Engr.	15.1	5.3	15.1	5.5
Sustaining Spares	23.1	8.2	24.8	9.1
Recertification	67.1	23.7	66.4	24.4
Fee	21.1	7.5	19.8	7.3
Program Office Management	16.0	5.7	15.4	5.7
Total Operations	$283.1		$272.2	



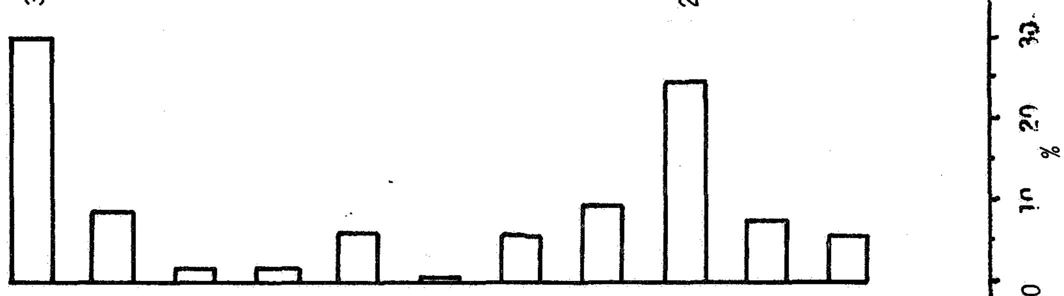


FIGURE 4-11

OPERATIONAL COST SUMMARY   MILLIONS OF 1969 DOLLARS

Constant Length Concept S 8M Total Payload Intermediate Philosophy

Payload Size = 50,000 Lbs.	Orbiter		Booster	
Launch Operations	$135.4	9.7%	$150.7	10.7%
Launch Area Support	88.6	6.3	86.9	6.1
Training & Mission Support	6.8	0.5	6.8	0.5
AGE & Facility Maintenance	10.0	0.7	9.1	0.6
Recovery	32.8	2.3	32.8	2.3
Transportation	23.6	1.7	23.6	1.7
Tech. Support & Sustaining Engr.	18.1	1.3	18.1	1.3
Sustaining Spares	41.9	3.0	38.9	2.8
Recertification	848.6	60.7	850.6	60.2
Fee	112.6	8.1	114.3	8.1
Program Office Management	79.1	5.7	79.9	5.7
Total Operations	$1397.5			

% (bar scale 0 10 20 30 40 50 60)

FIGURE 4-12

OPERATIONAL COST SUMMARY   MILLIONS OF 1969 DOLLARS

Constant Length Concept S 8M Total Payload BAU Philosophy

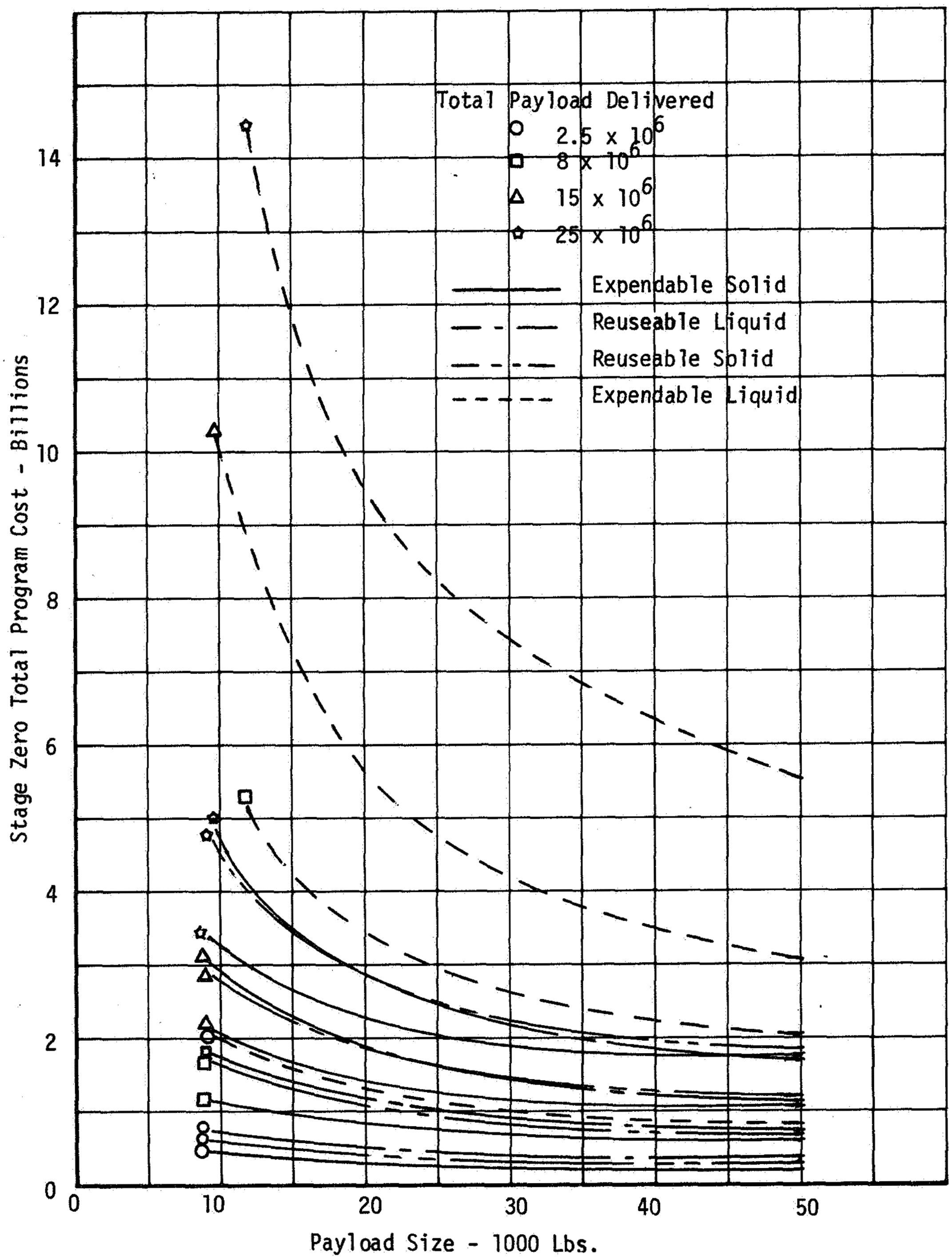
Payload Size = 50,000 Lbs.	Orbiter	%	Booster	%
Launch Operations	$306.4	11.2	$363.4	13.1
Launch Area Support	241.8	8.9	237.3	8.6
Training & Mission Support	13.3	0.5	13.3	0.5
AGE & Facility Maintenance	22.9	0.9	20.8	0.7
Recovery	33.4	1.2	33.4	1.2
Transportation	25.6	0.9	25.6	0.9
Tech. Support & Sustaining Engr.	25.2	0.9	25.1	0.9
Sustaining Spares	79.5	2.9	73.7	2.7
Recertification	1596.1	58.6	1587.3	57.4
Fee	226.2	8.3	230.2	8.3
Program Office Management	154.2	5.7	156.6	5.7
Total Operations	$2724.6		$2766.7	

0 10 20 30 40 50 60 %

FIGURE 4-13

STAGE ZERO TOTAL COST VS. PAYLOAD SIZE

Constant Length Concept S



STAGE ZERO RECURRING COST VS. PAYLOAD SIZE

Constant Length Concept S

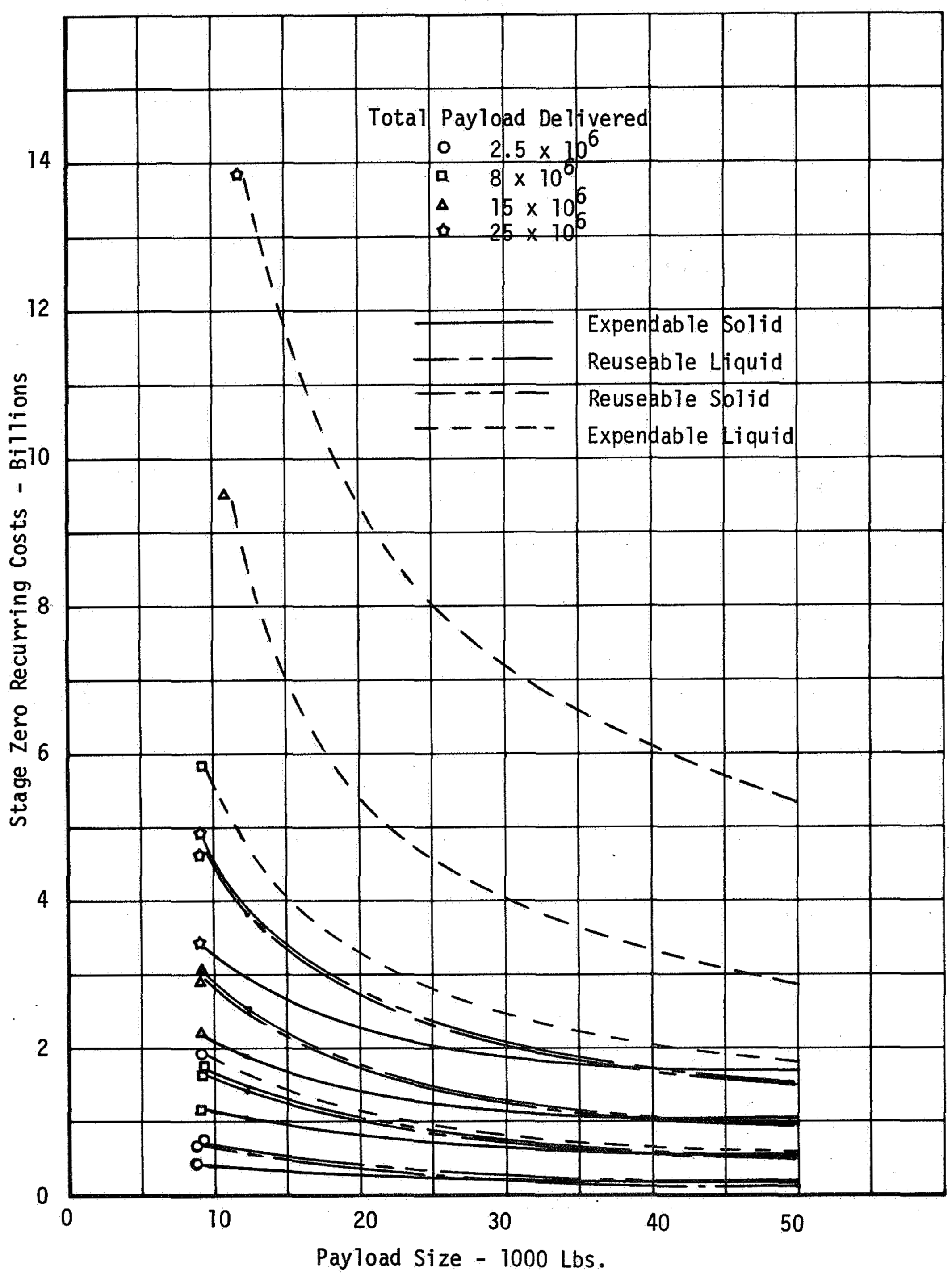


FIGURE4-15

STAGE ZERO RECURRING COSTS VS. NUMBER OF FLIGHTS
Constant Length Concept S

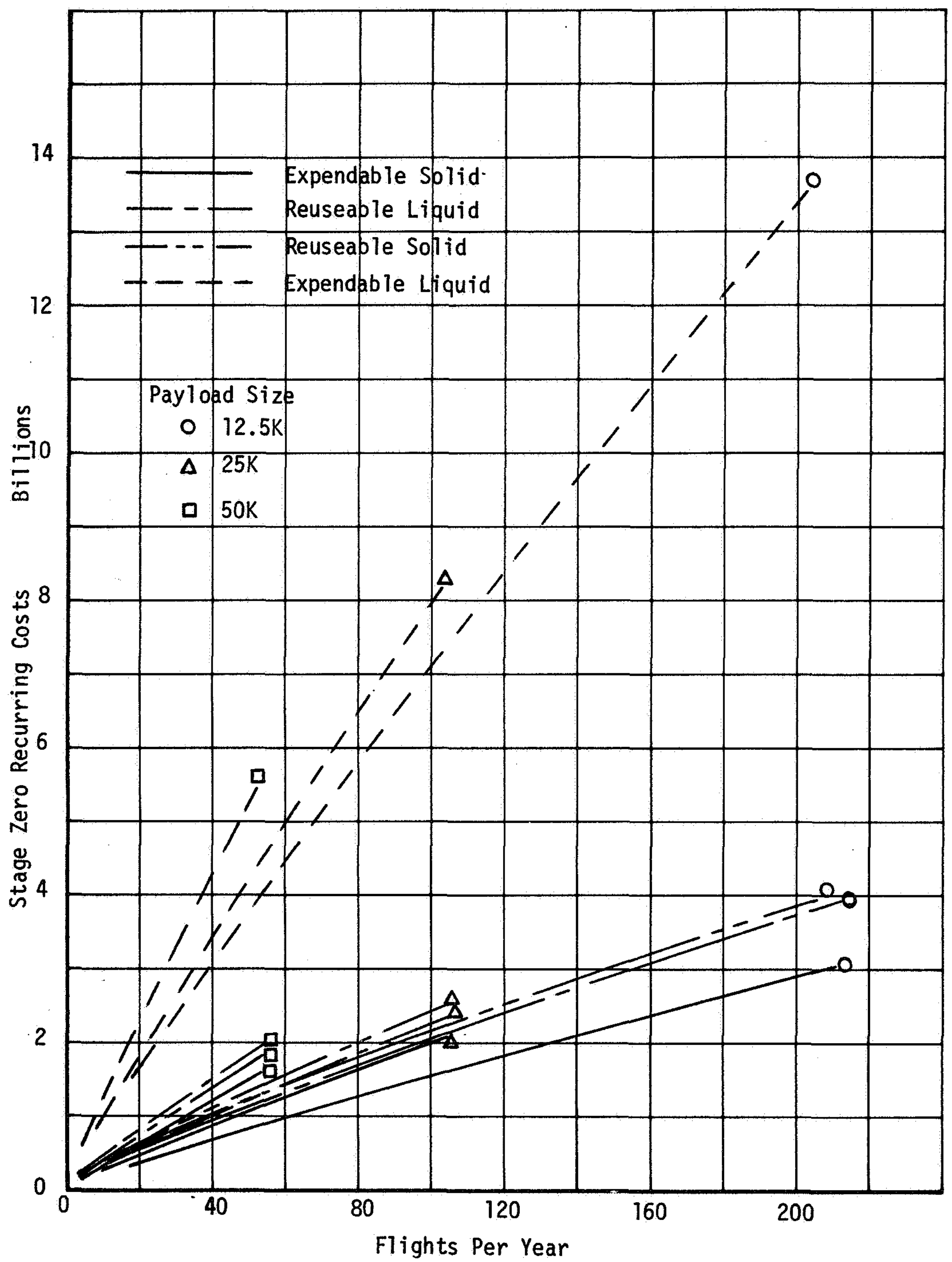


FIGURE 4-16

ZERO STAGE RECURRING COSTS PER FLIGHT VS. FLIGHTS PER YEAR

Concept S - Constant Length = 165 Ft.

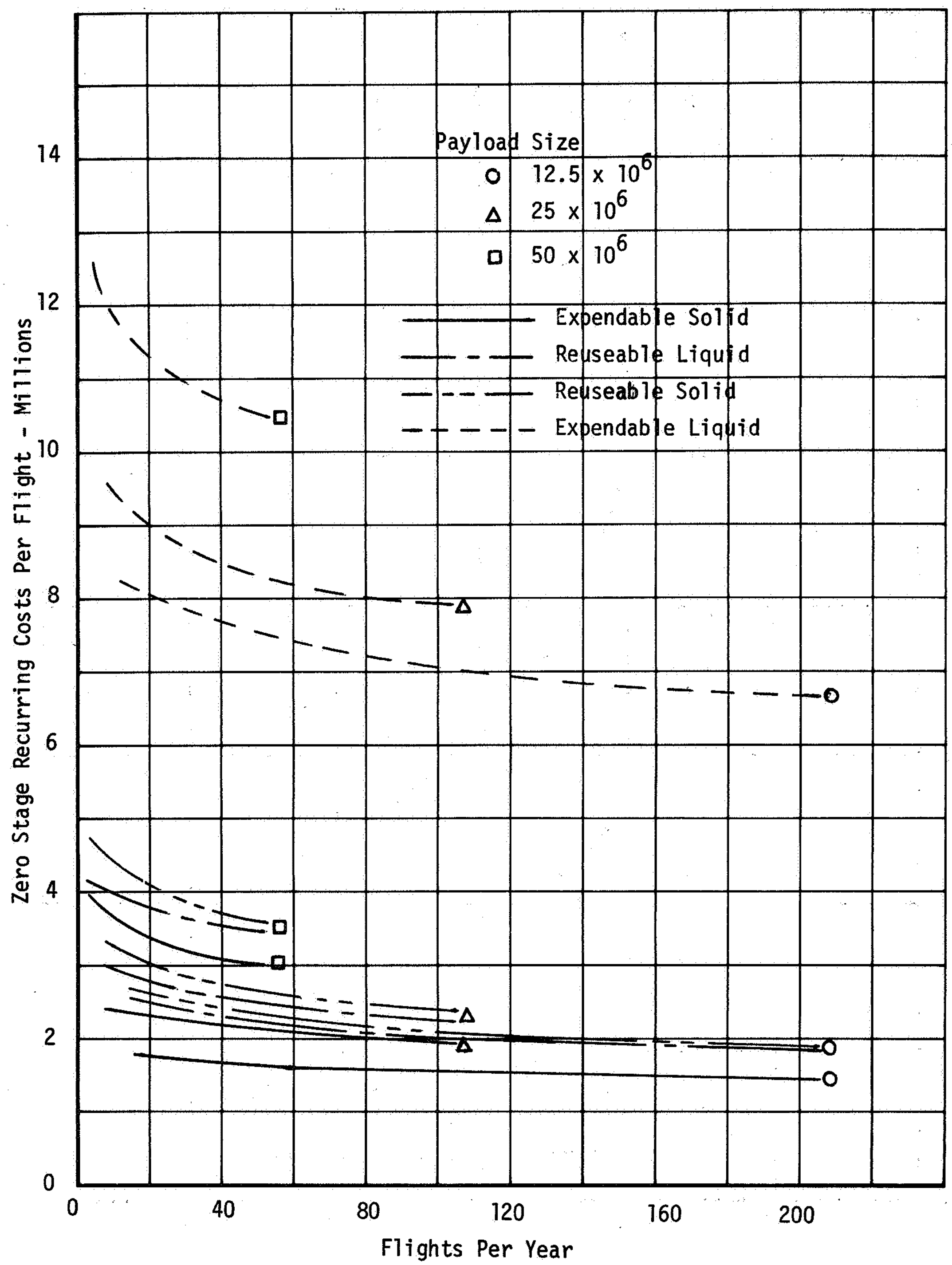


FIGURE 4-17

TOTAL PROGRAM COST VS. PAYLOAD SIZE

Concept S, Zero Stage Expendable Solid, ΔV = 18,790

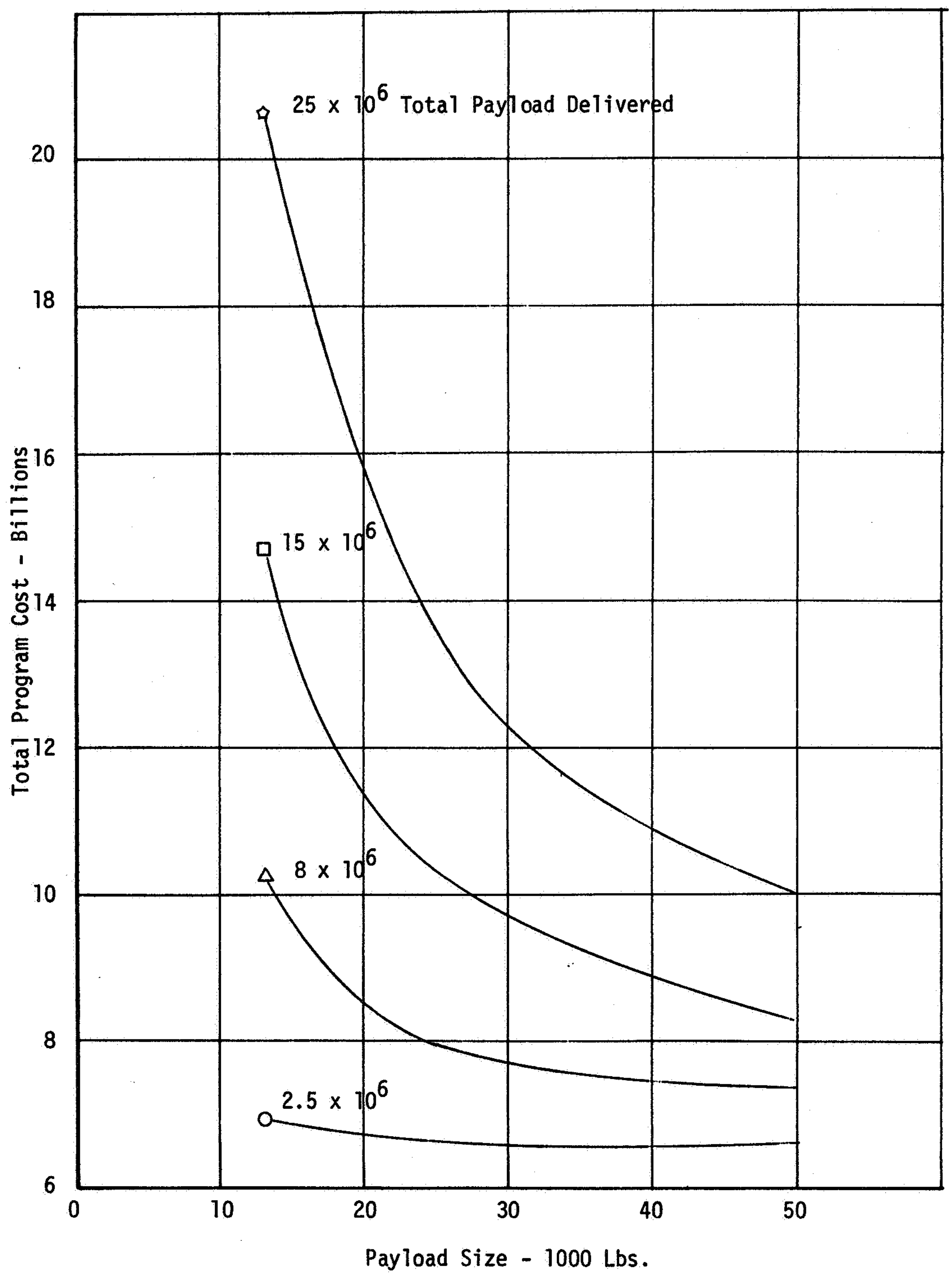


FIGURE 4-18

RECURRING COST VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 18,790

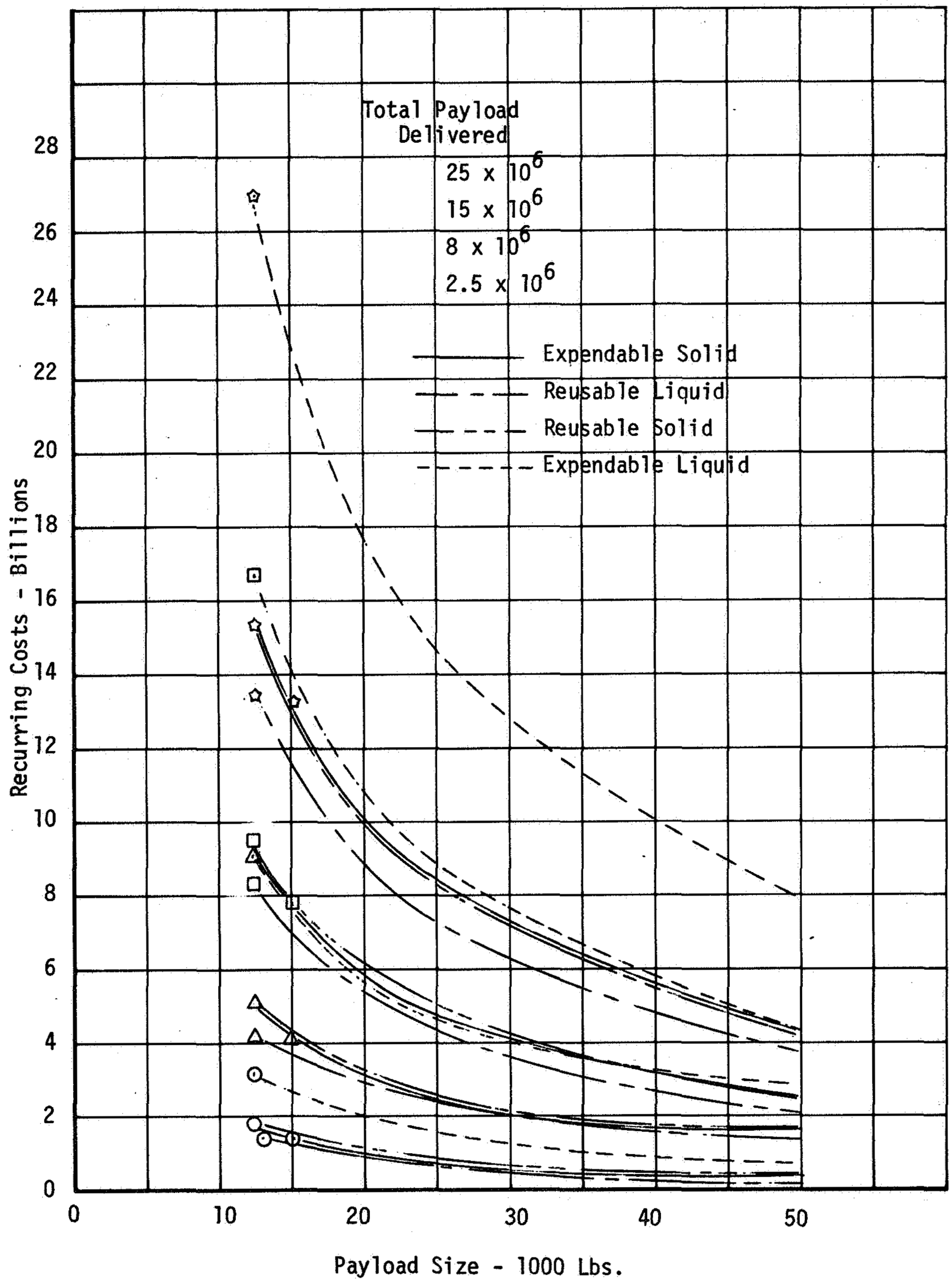


FIGURE 4-19

RECURRING COST PER FLIGHT VS. FLIGHTS PER YEAR

Concept S, Orbiter Constant ΔV = 18,790

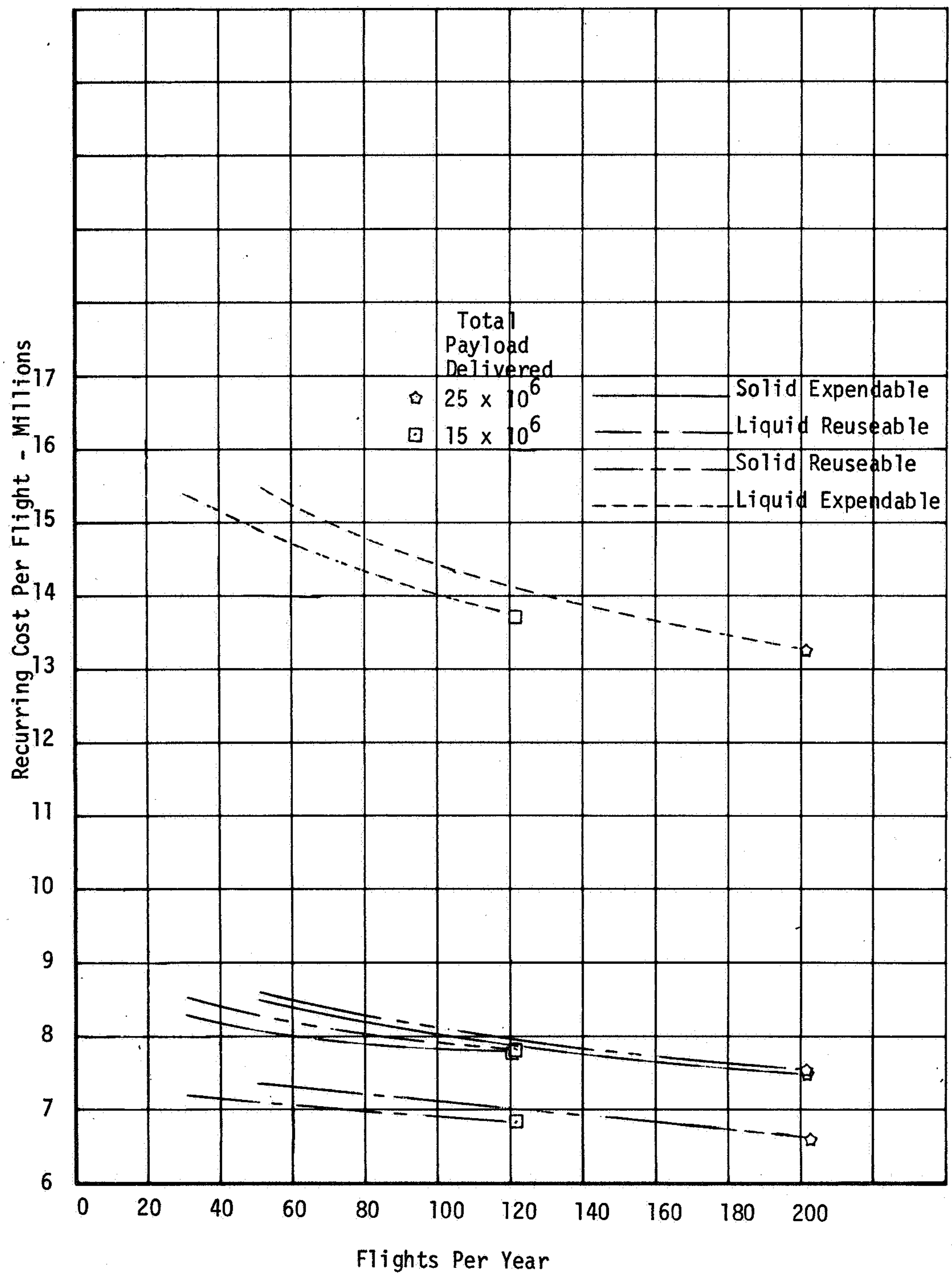


FIGURE 4-20

TOTAL STAGE ZERO PROGRAM COST VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 18,790

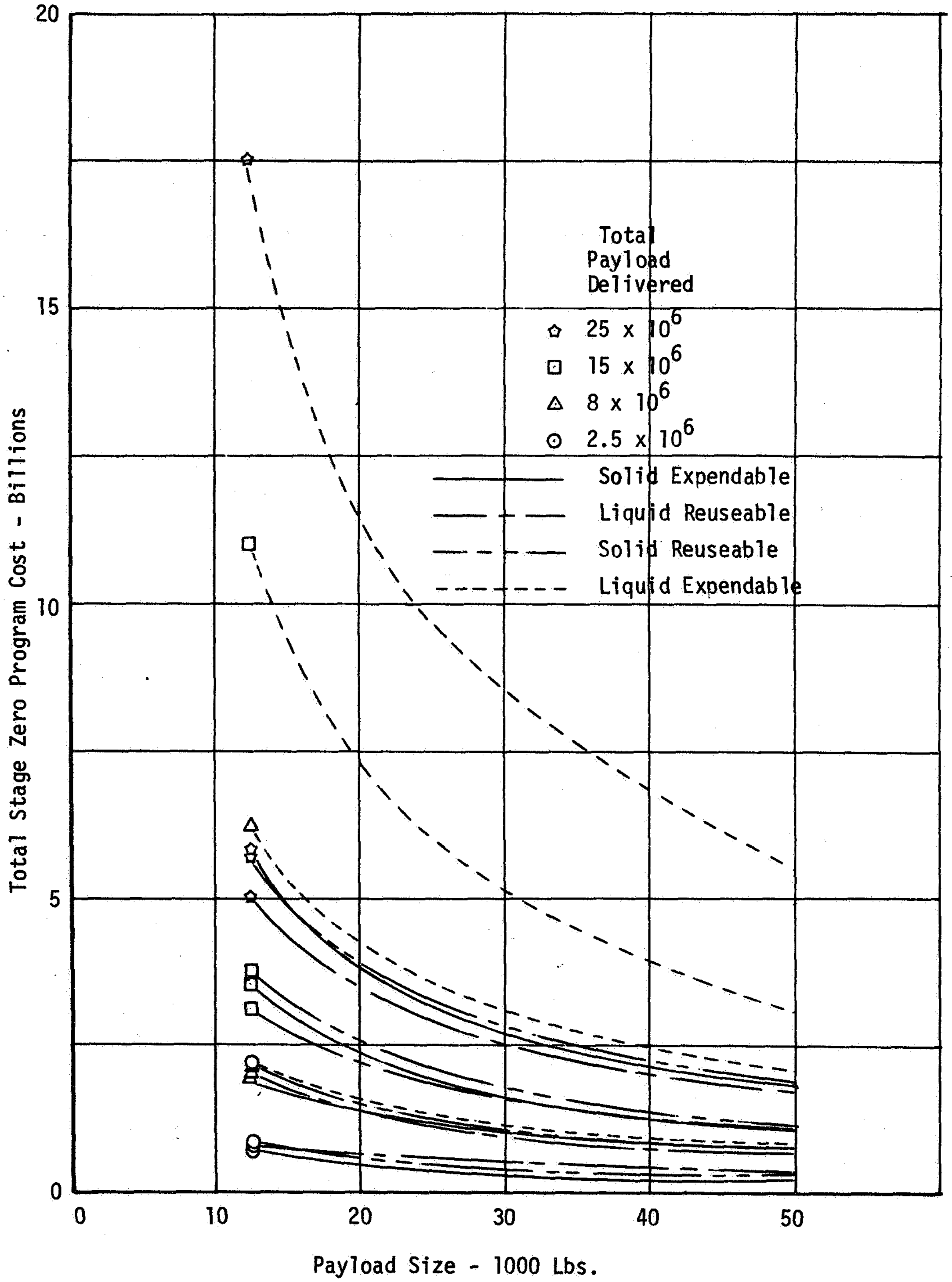


FIGURE 4-21

ZERO STAGE RECURRING COSTS VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 18,790

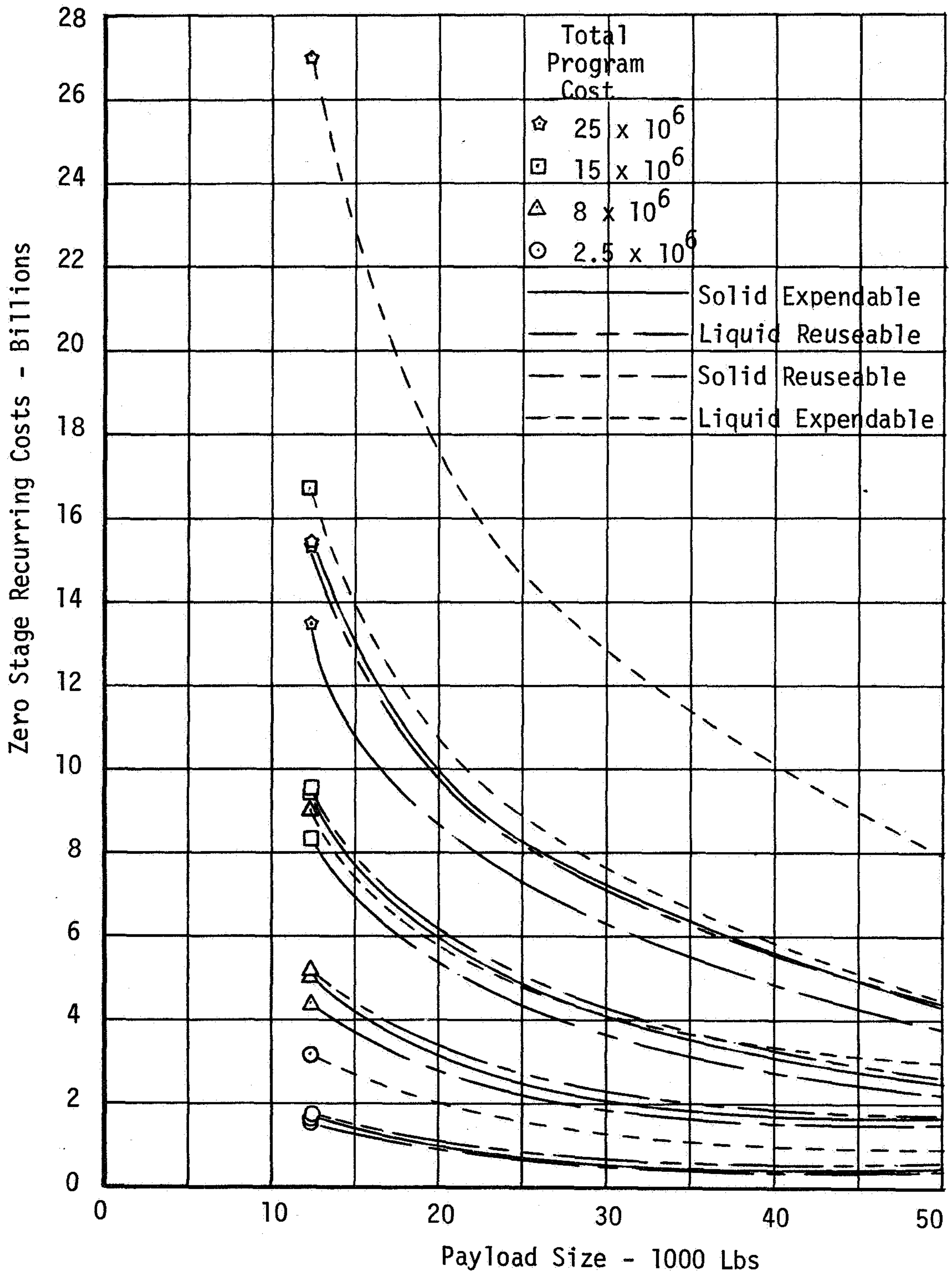


FIGURE 4-22

ZERO STAGE RECURRING COSTS VS. FLIGHTS PER YEAR

Concept S, Orbiter Constant ΔV = 18,790

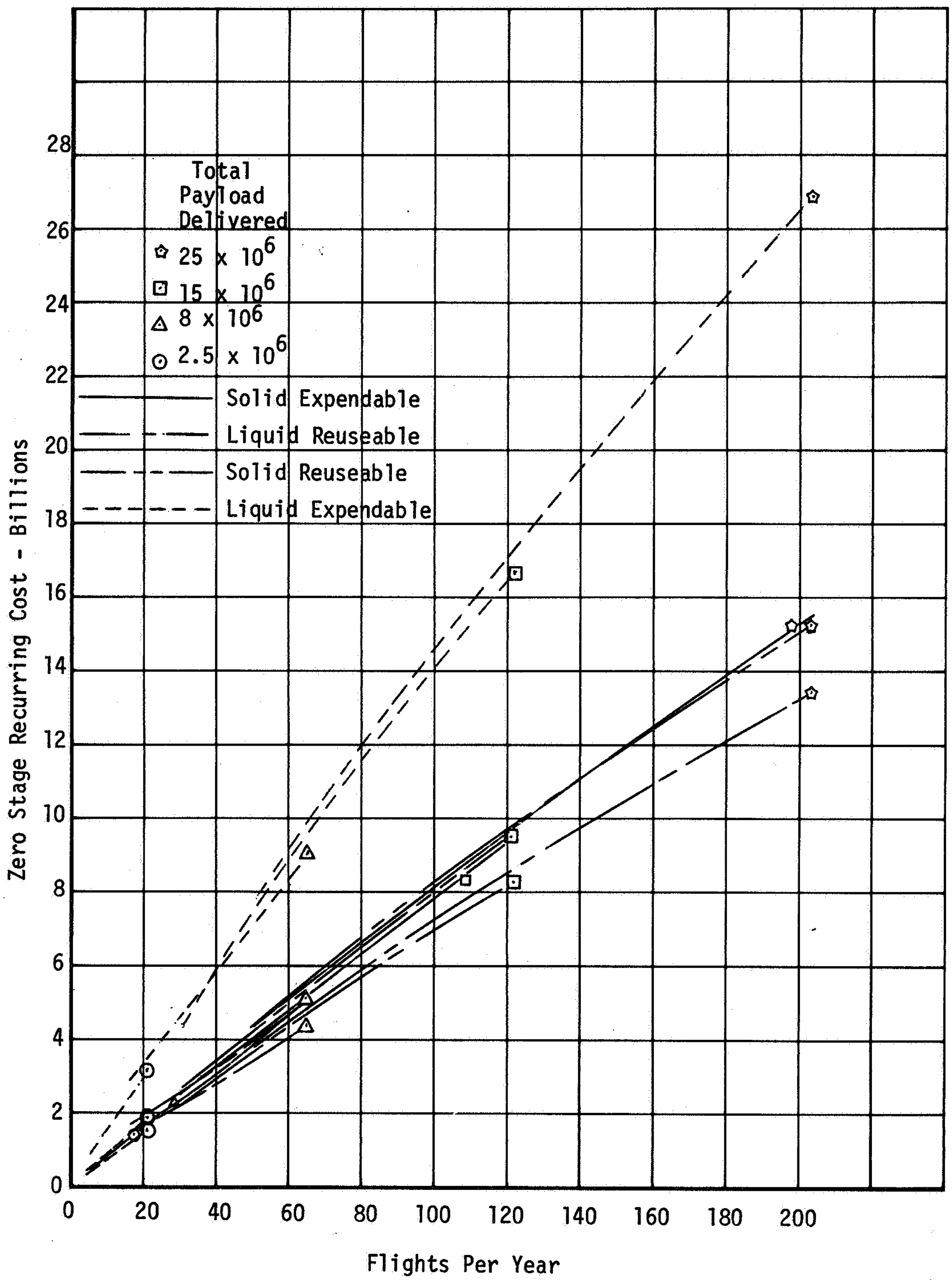


FIGURE 4-23

STAGE ZERO RECURRING COST PER FLIGHT VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 18,790

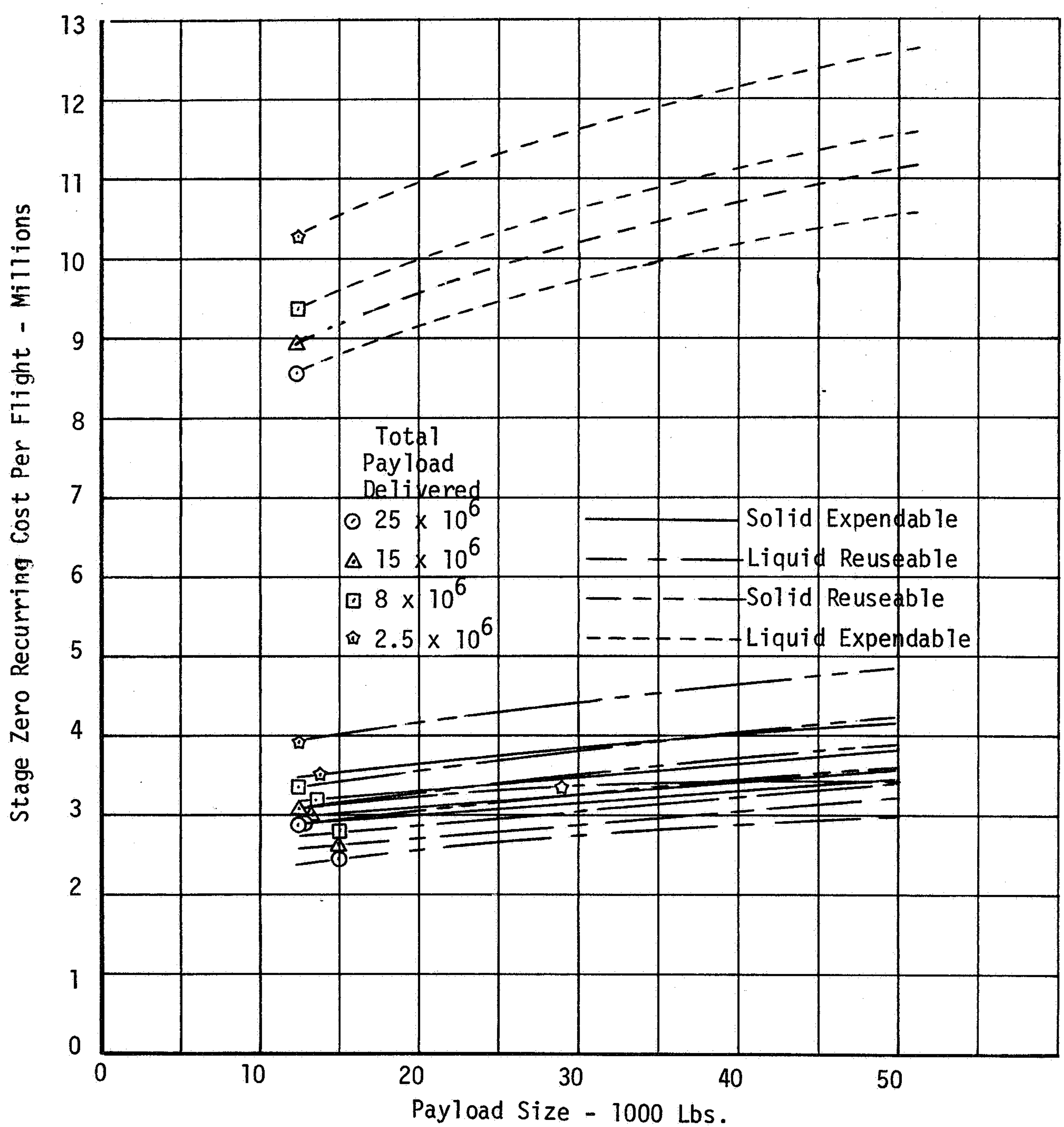


FIGURE 4-24

TOTAL PROGRAM COST VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 20,890 FPS

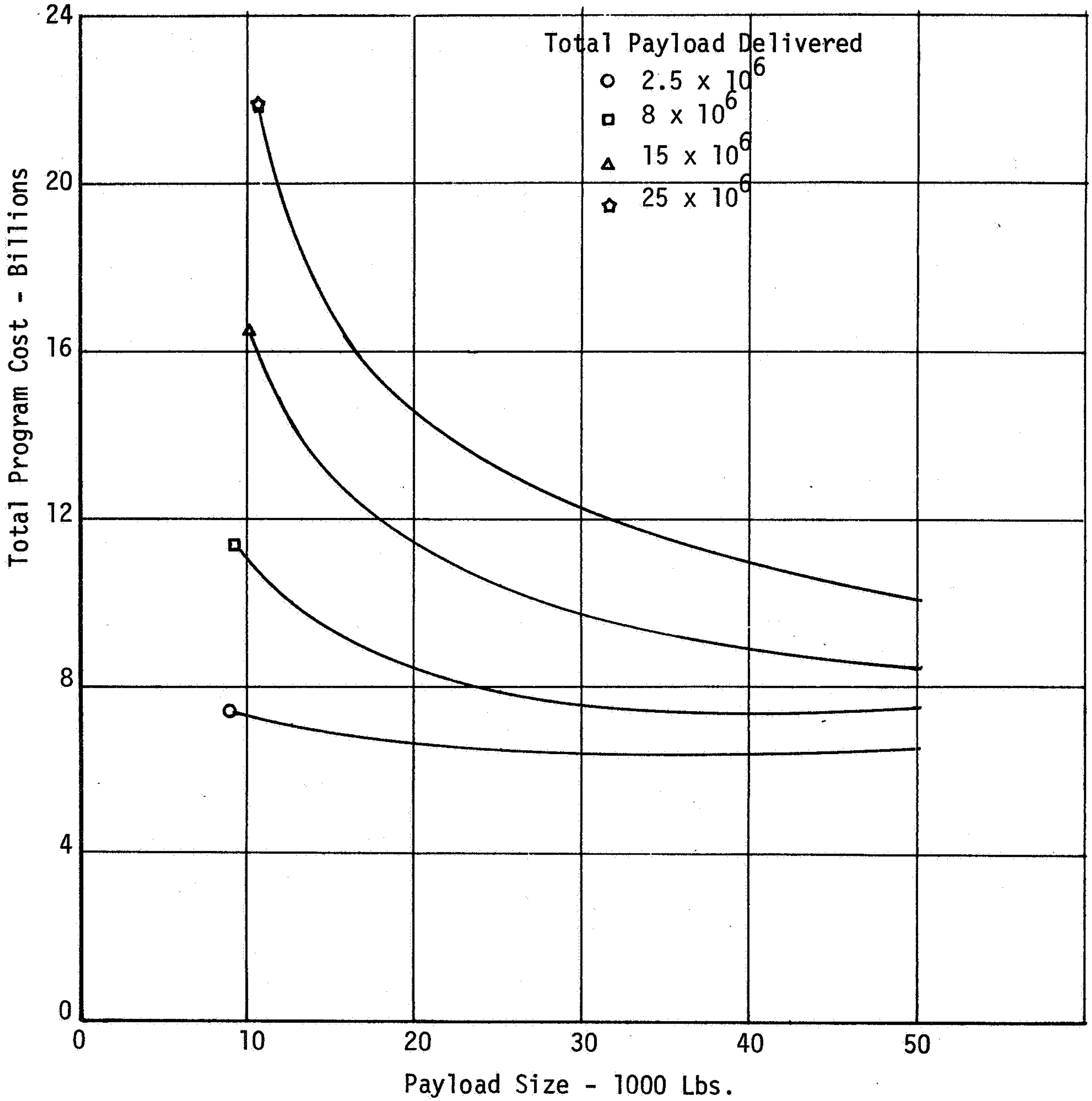


FIGURE 4-25

RECURRING COST VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 20,890 FPS

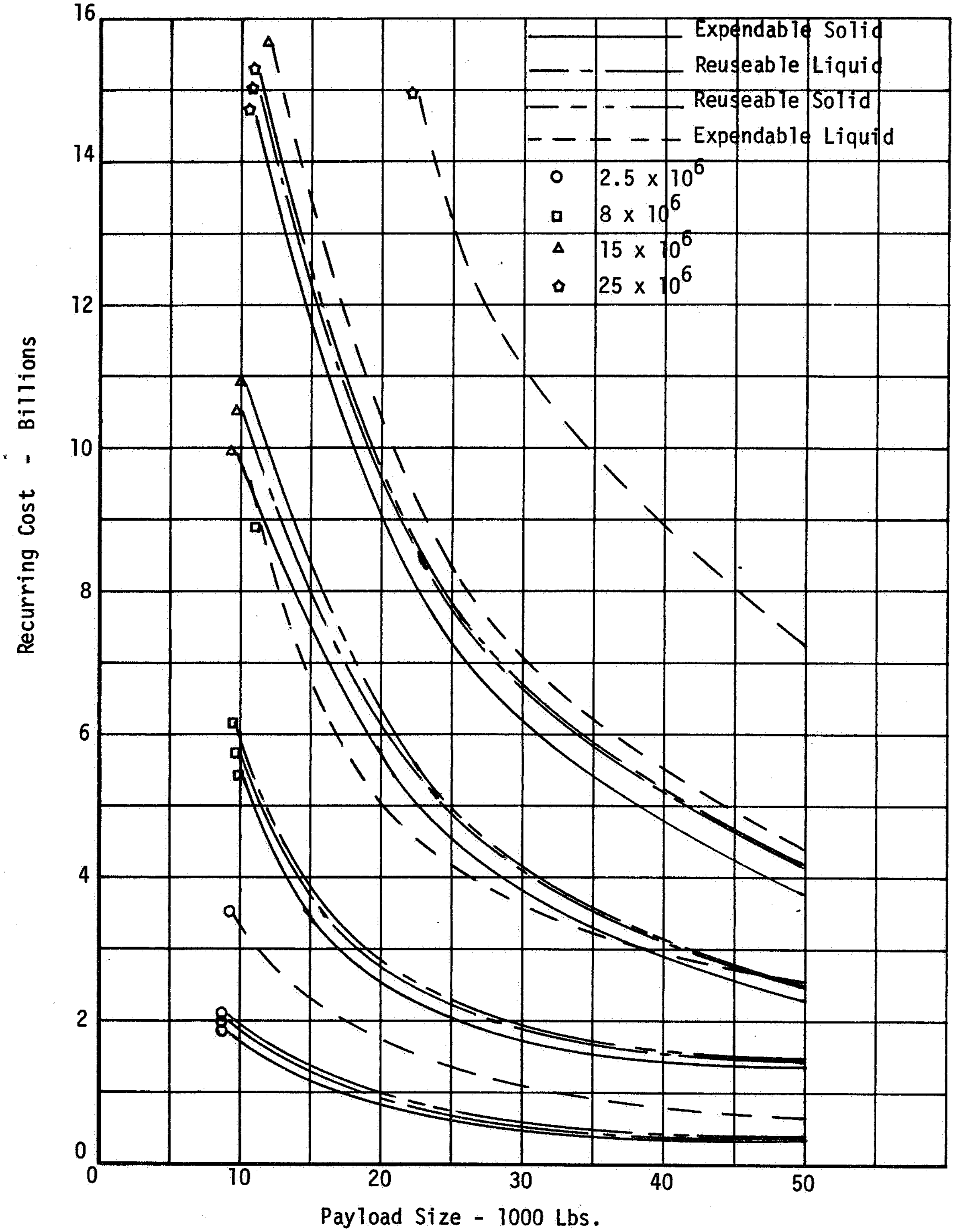


FIGURE 4-26

ZERO STAGE TOTAL PROGRAM COST VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 20,890 FPS

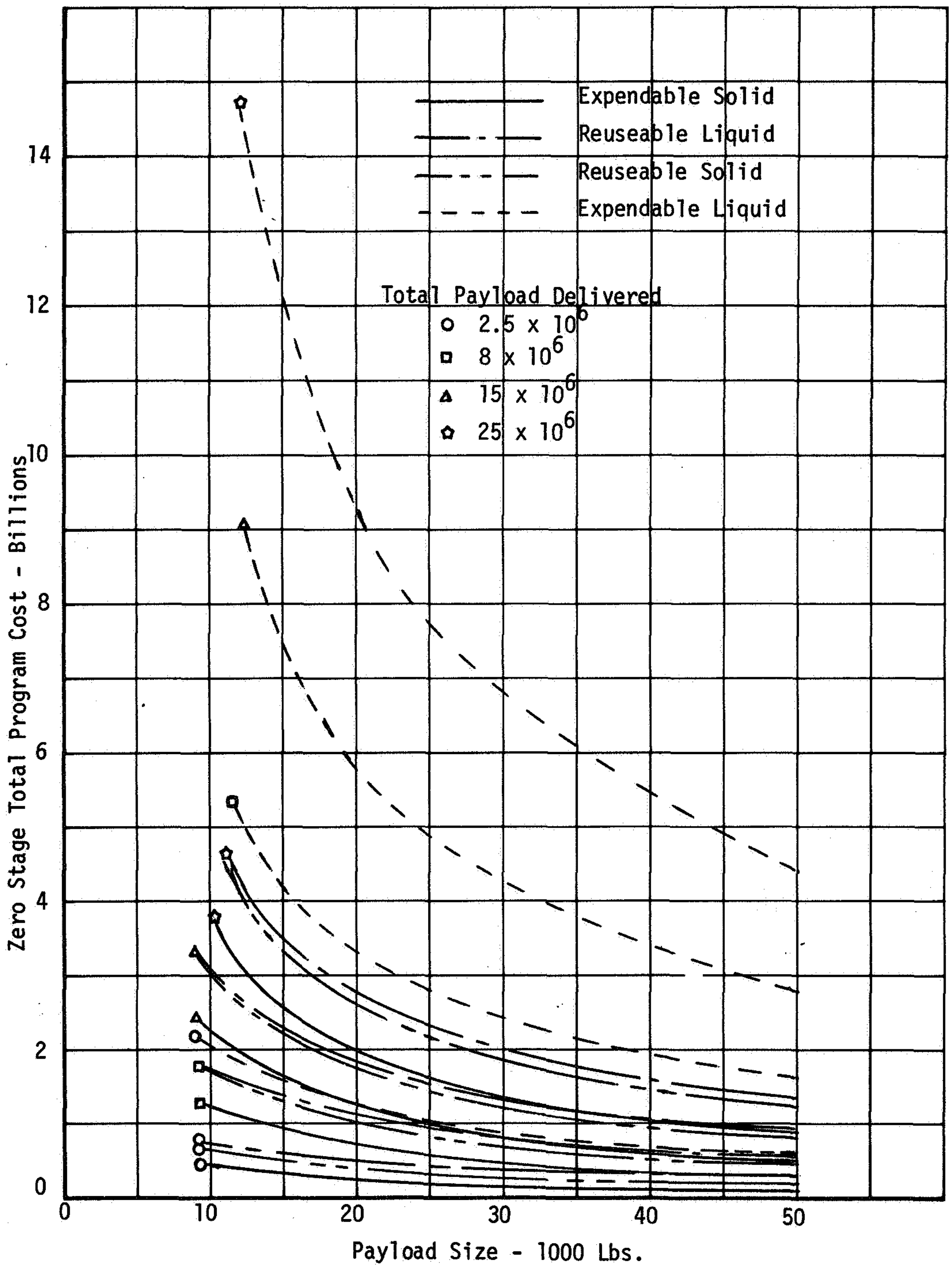


FIGURE 4-27

STAGE ZERO RECURRING COST VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 20,890 FPS

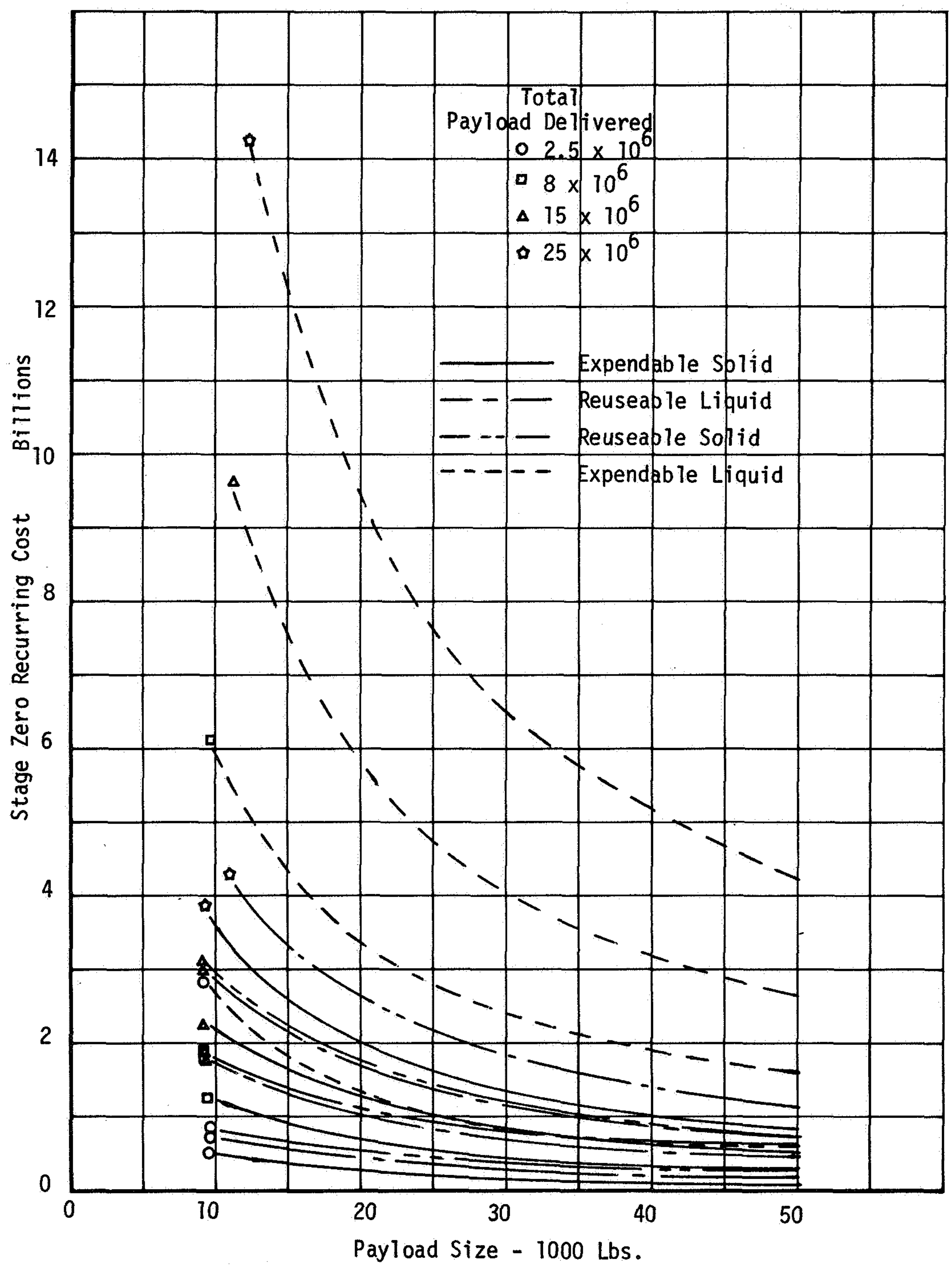


FIGURE 4-28

ZERO STAGE RECURRING COST VS. NUMBER OF FLIGHTS

Concept S, Orbiter Constant ΔV = 20,890 FPS

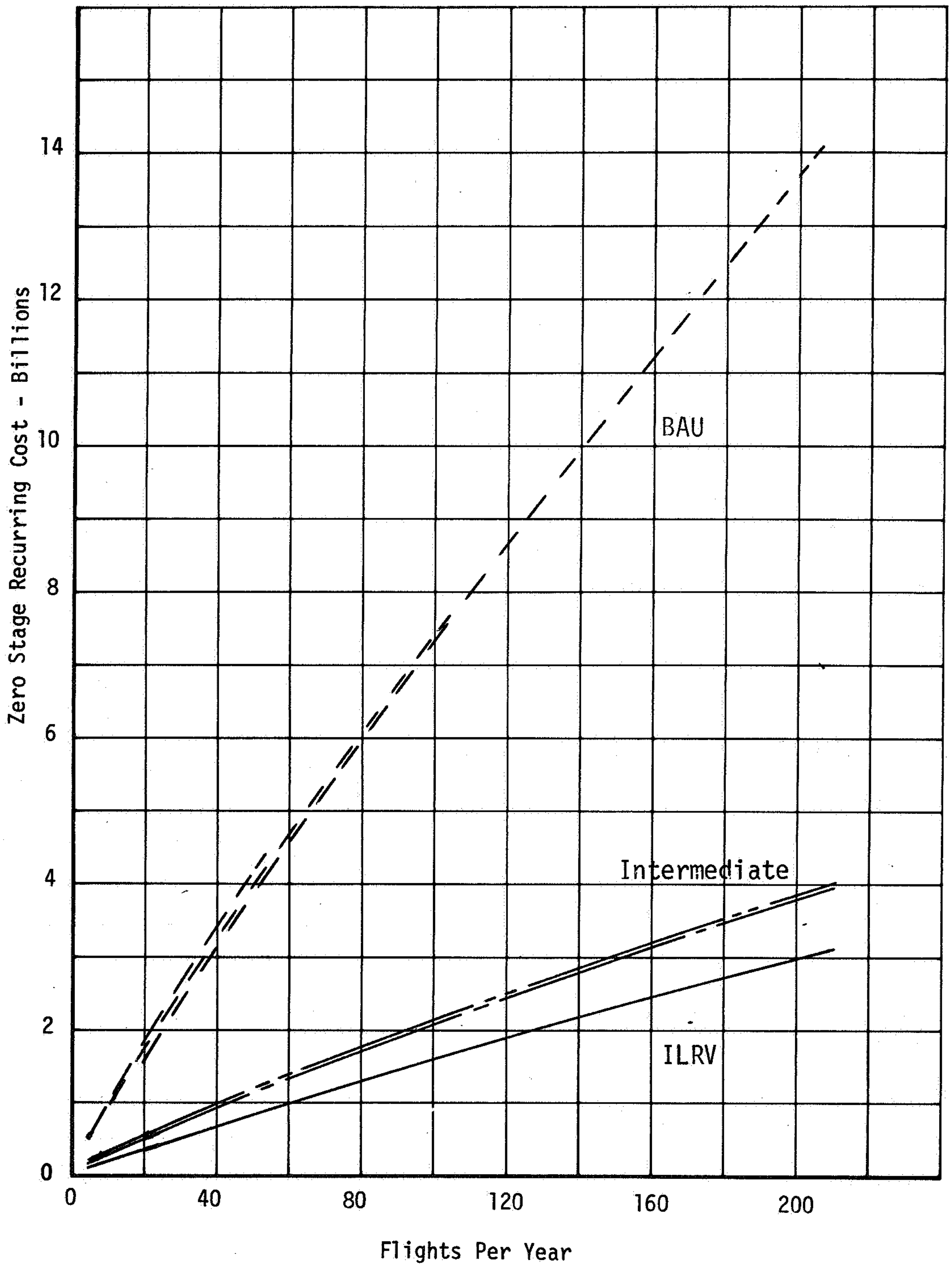


FIGURE 4-29

ZERO STAGE RECURRING COST PER FLIGHT VS. PAYLOAD SIZE

Concept S, Orbiter Constant ΔV = 20,890 FPS

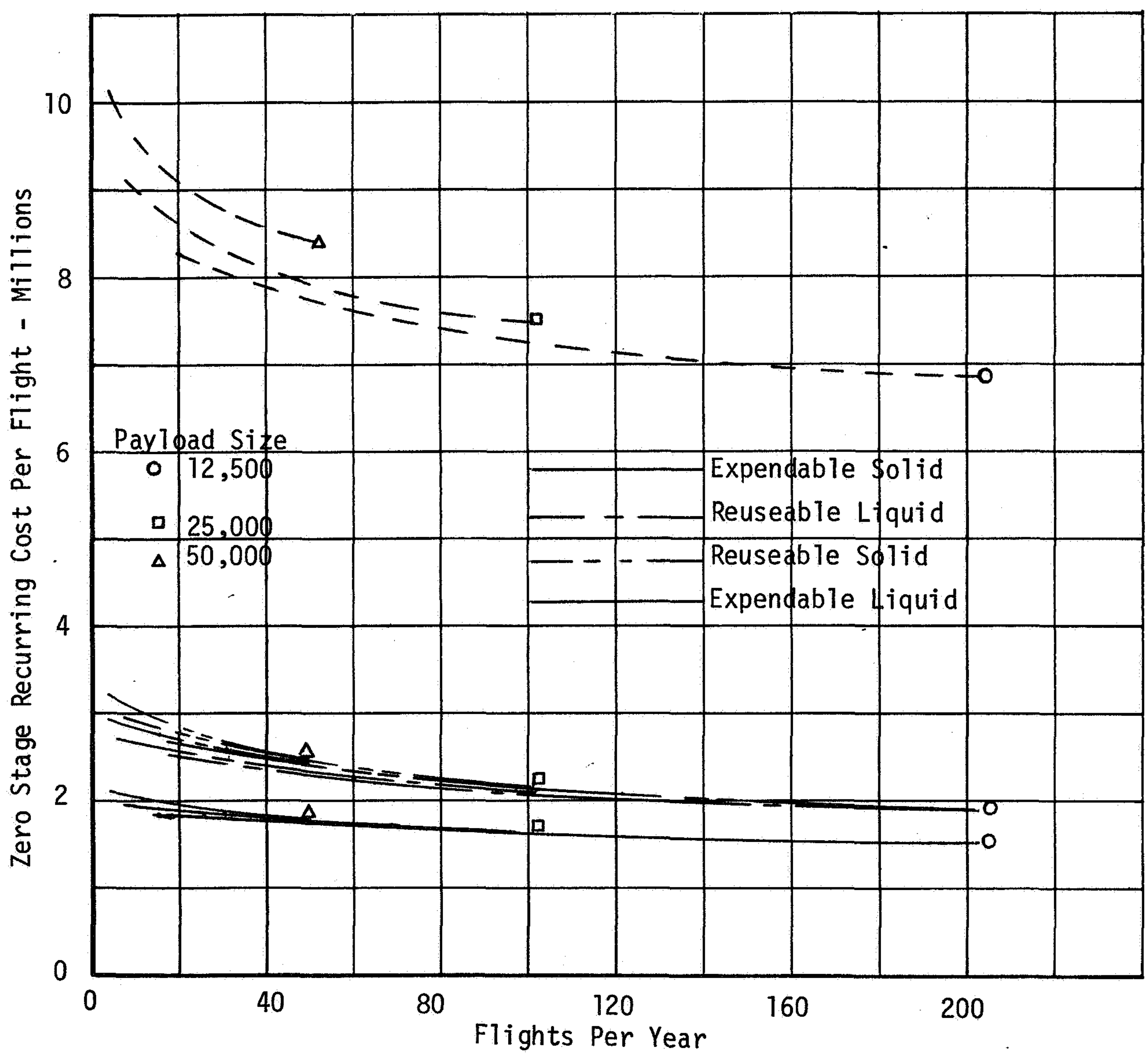


FIGURE 4-30

4.4.2 Concept "L" - Concept "L" is a more conventional orbiter-booster combination. The cost trends as shown in Figure 4-31 of total program costs versus payload size are similar to the data of Concept "S". The minimum cost payload size for the ILRV operational philosophy approach is around 30,000 pounds and for the BAU operational philosophy around 50,000 pounds. Both optimum sizes increase as the traffic or total payload delivered increases.

Payload size has some effect on total cost is shown by Figure 4-32. The trend of total cost as a function of the flights per year are nearly linear indicating that there is only a small quantity improvement factor.

Recurring costs are shown in Figure 4-33 through 4-35. There seems to be a band of costs for the recurring costs as a function of the number of flights per year, particularly for the ILRV operational philosophy, which is insensitive to the payload size. There is also some scatter in the ILRV data for the recurring cost versus payload size due to the sensitivity of the model used. The trend of increasing recurring costs per flight with increased traffic reflects the increased unit recertification costs for the higher usage experienced by each vehicle. The recertification model used attempts to reflect a scheduled maintenance program with relatively uniform costs per cycle upon which is superimposed a high cost upon completion of 25 flights reflecting replacement of life-limited items. This tends to raise the recertification costs per flight as the vehicle makes more flights.

Figure 4-36, 4-37 and 4-38 present the breakdown of the operational costs for each of the three operational philosophies. As before, the launch operations and the recertification are the two major cost centers.

4.4.3 Concept "M" - Concept "M" data is inconsistent for the lower payload size. This is probably due to the over optimistic design noted previously. The ILRV philosophy data shown in Figure 4-39 indicates increasing rather than decreasing total program costs as the payload size is increased for a fixed total payload delivered. This is not consistent with experience and indicates that the costs estimated are low for the 12,500 pound payload size. The trends of total program costs and recurring costs should be similar to Concept "L" and Concept "S" data trends. However, the data developed is presented in Figures 4-40 through 4-43. It should be noted that since the curves are based on only three data points trends can be somewhat misleading at times. The operational cost breakdown for the three operating philosophies is shown in Figures 4-44, 4-45 and 4-46.

TOTAL COST VS. PAYLOAD SIZE

Concept L

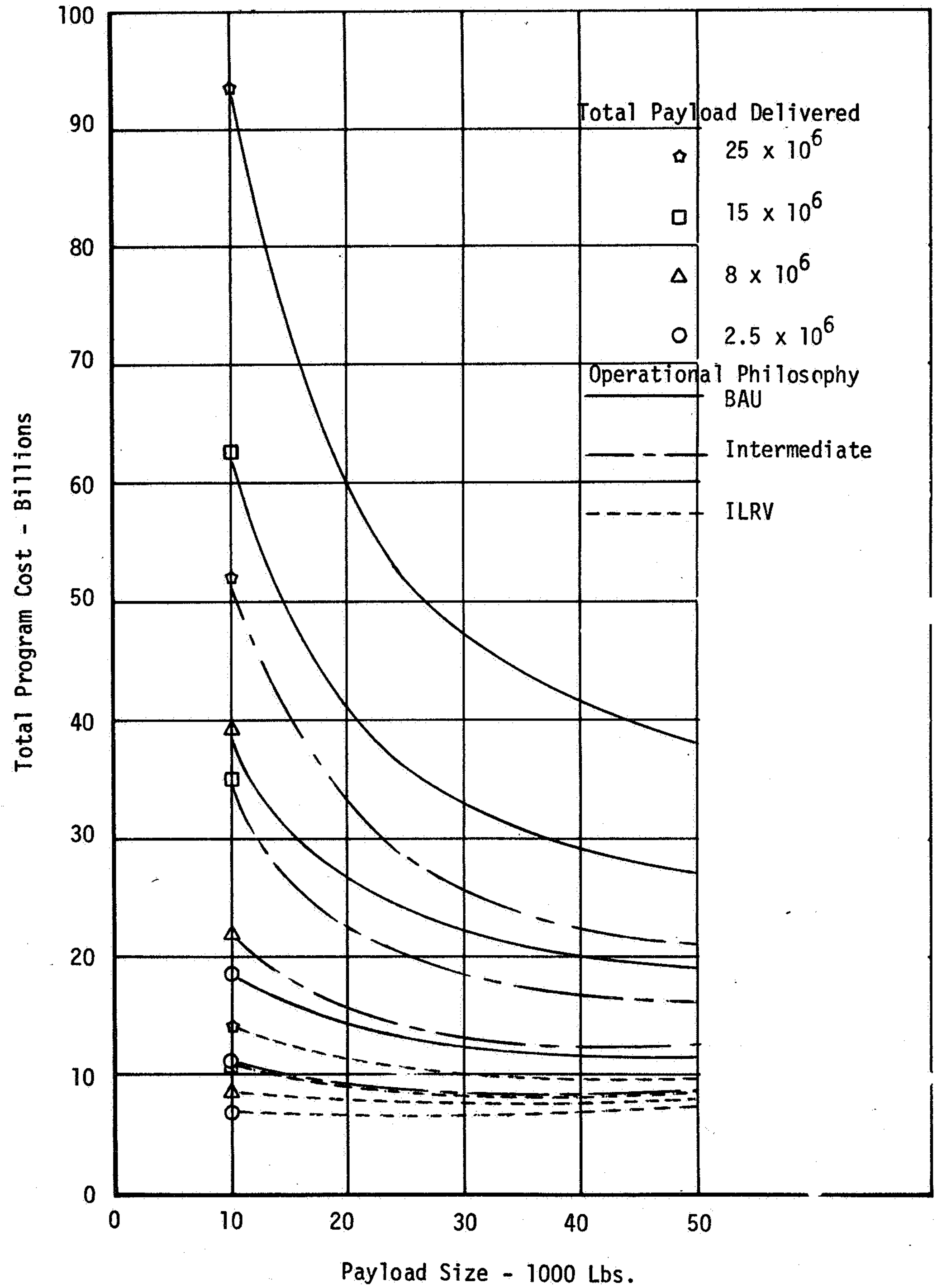


FIGURE 4-31

TOTAL COST VS. FLIGHTS PER YEAR

Concept L

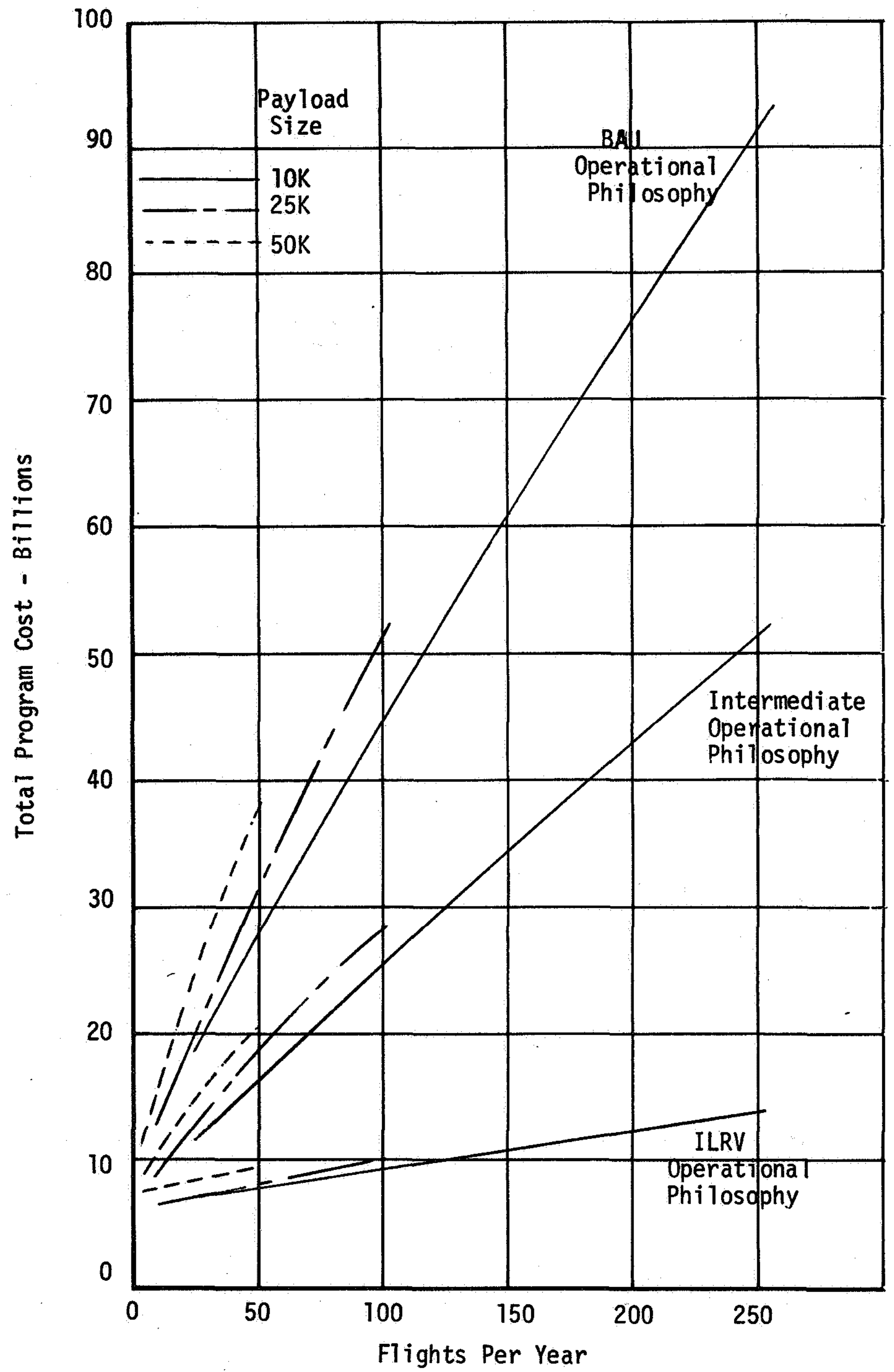


FIGURE 4-32

RECURRING COSTS VS. PAYLOAD SIZE

Concept L

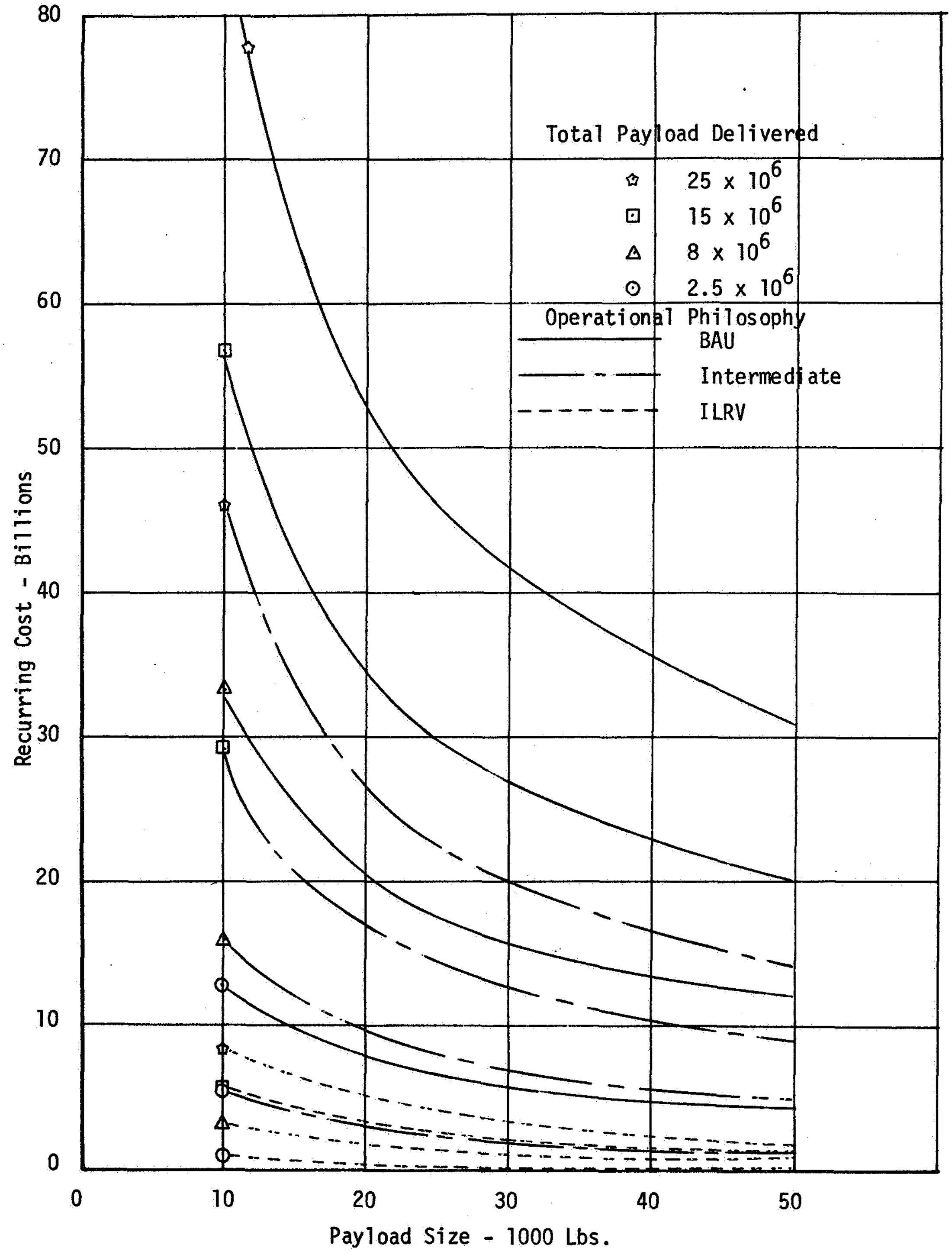


FIGURE 4-33

RECURRING COST PER FLIGHT VS. FLIGHTS PER YEAR

Concept L

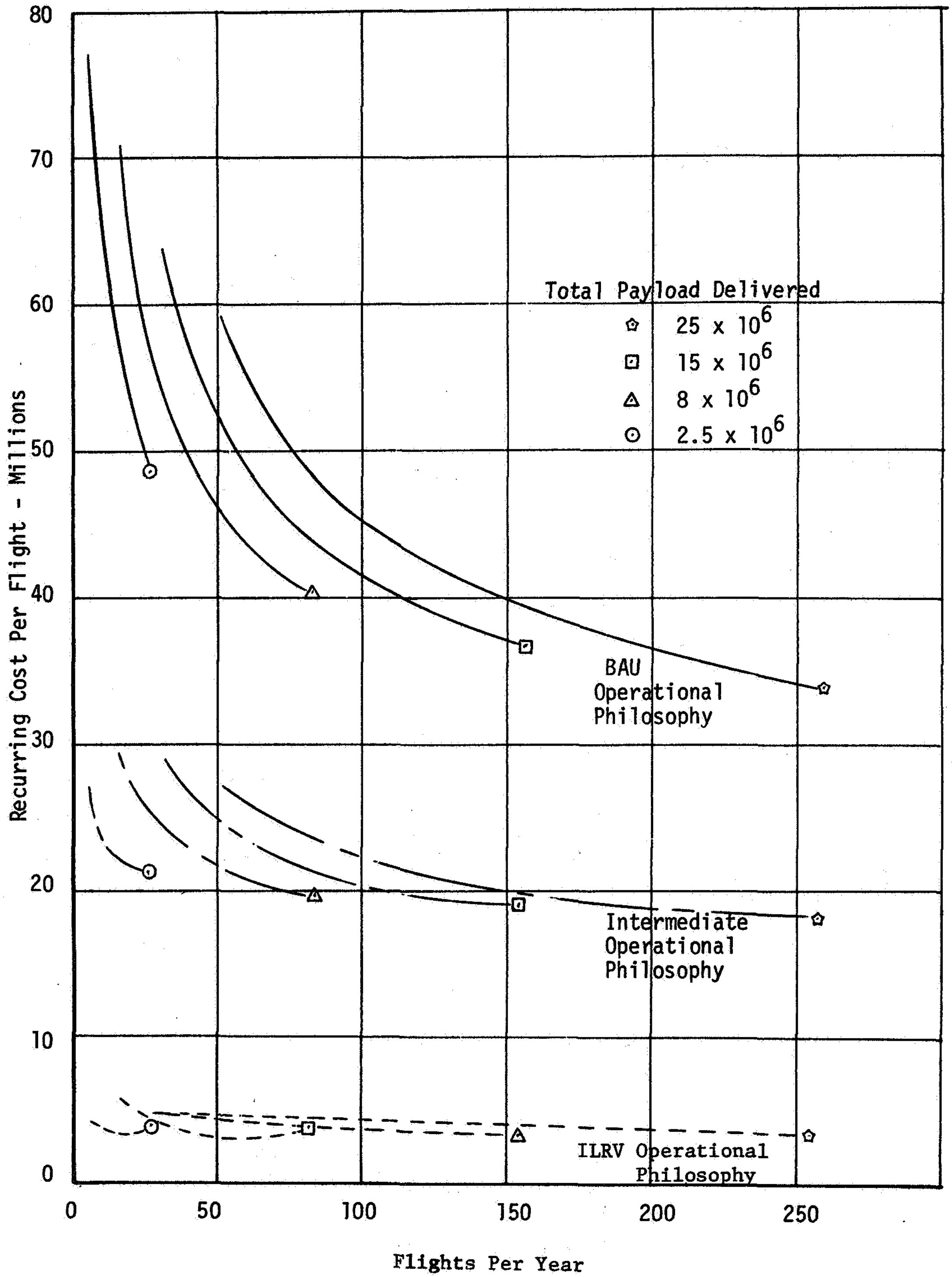


FIGURE 4-34

RECURRING COST PER FLIGHT VS. PAYLOAD SIZE

Concept L

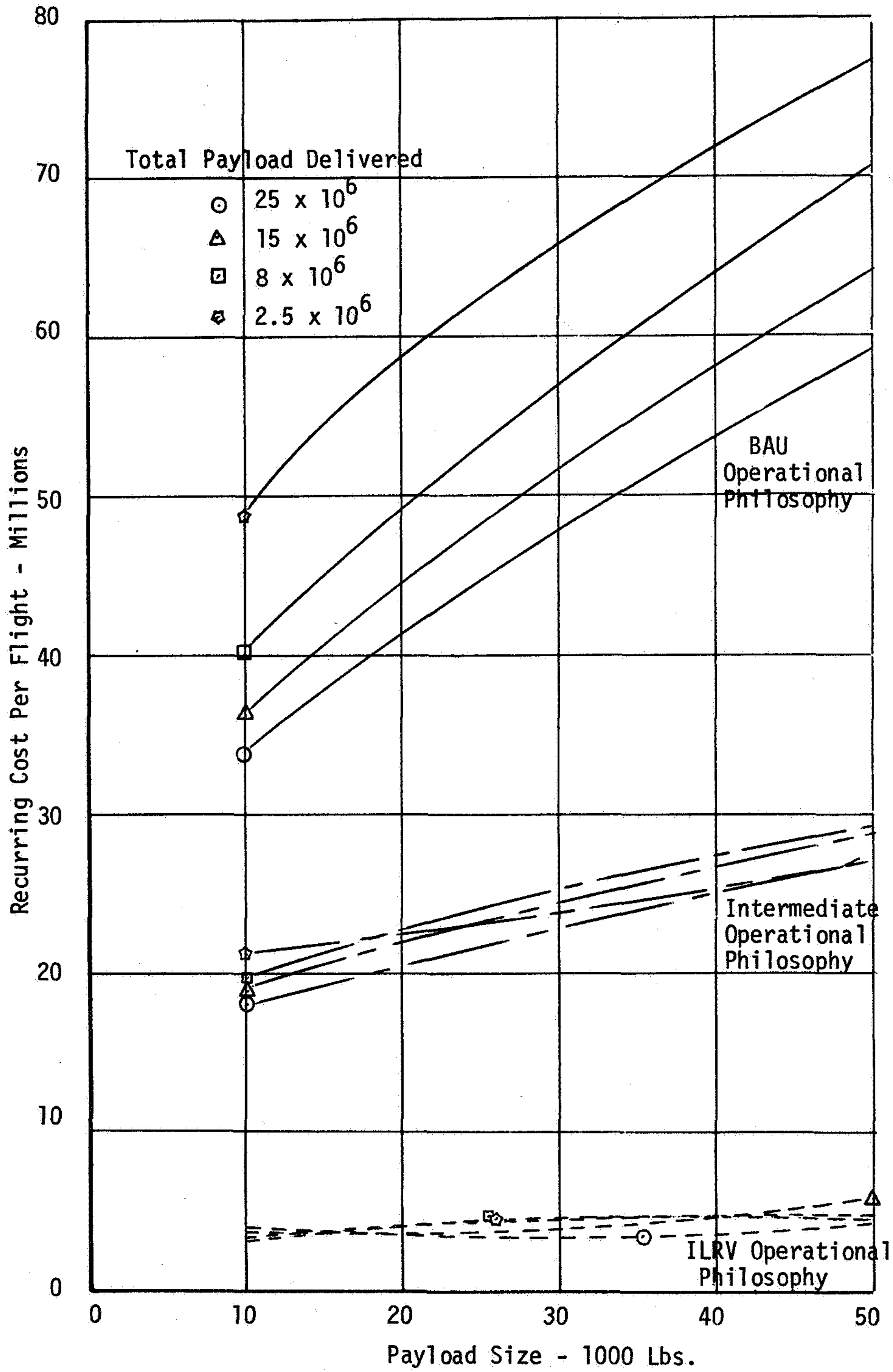


FIGURE 4-35

OPERATIONAL COST SUMMARY MILLIONS OF 1969 DOLLARS

Concept L 8M Total Payload ILRV Philosophy

Payload Size = 50,000 Lbs.	Orbiter ($)	Orbiter (%)	Booster ($)	Booster (%)
Launch Operations	$111.5	35.1%	$ 79.6	33.1%
Launch Area Support	23.5	7.4	19.6	8.2
Training & Mission Support	4.0	1.2	4.0	1.7
AGE & Facility Maintenance	4.5	1.4	3.7	1.6
Recovery	16.4	5.1	16.4	6.9
Transportation	0.3	0.1	0.3	0.1
Tech. Support & Sustaining Engr.	14.9	4.7	11.8	4.9
Sustaining Spares	26.9	8.5	16.7	7.0
Recertification	77.0	24.2	55.8	23.4
Fee	20.9	6.6	17.3	7.2
Program Office Management	18.0	5.7	13.5	5.7
Total Operations	$317.9		$238.7	

0 10 20 30 %

FIGURE 4-36

OPERATIONAL COST SUMMARY MILLIONS OF 1969 DOLLARS

Concept L 8M Total Payload Intermediate Philosophy

Payload Size = 50,000 Lbs.	Orbiter		Booster	
Launch Operations	$164.5	10.9%	$126.1	10.9%
Launch Area Support	86.3	5.7	73.0	6.3
Training & Mission Support	6.8	0.5	6.8	0.6
AGE & Facility Maintenance	9.0	0.6	8.1	0.7
Recovery	32.8	2.2	32.8	2.8
Transportation	23.8	1.6	23.6	2.0
Tech. Support & Sustaining Engr.	17.9	1.2	14.1	1.2
Sustaining Spares	42.0	2.8	28.2	2.4
Recertification	915.6	60.9	688.3	59.4
Fee	118.8	7.9	92.6	8.0
Program Office Management	85.1	5.7	65.6	5.7
Total Operations	$1502.6			

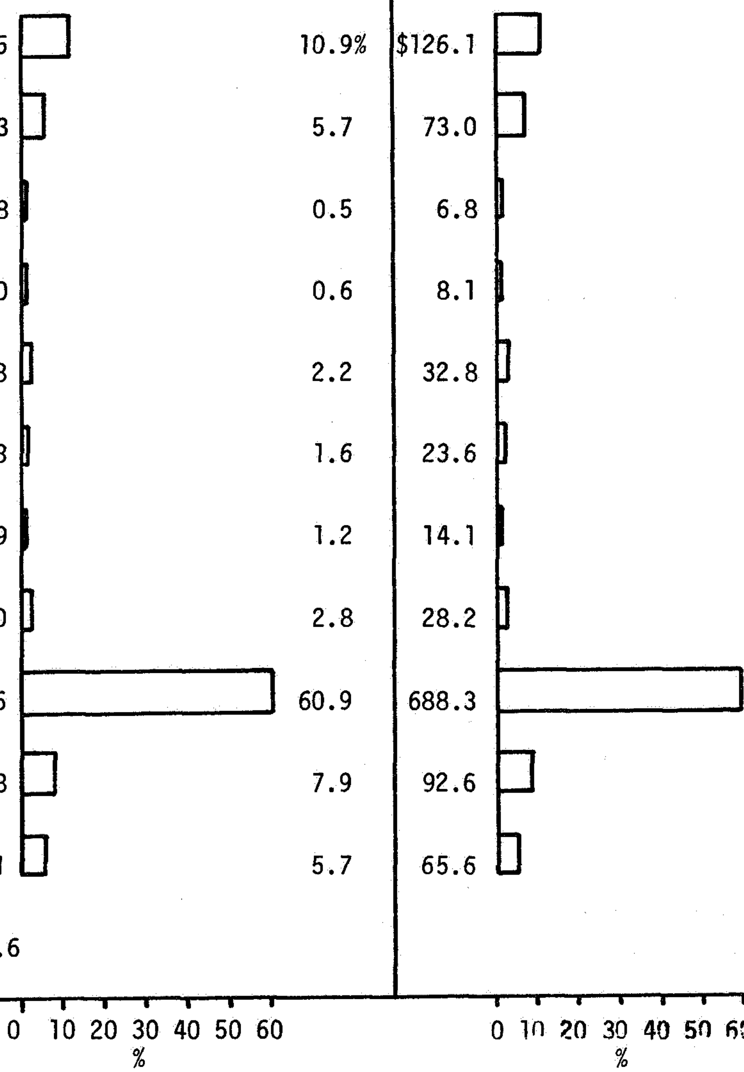


FIGURE 4-37

OPERATIONAL COST SUMMARY MILLIONS OF 1969 DOLLARS

Concept L 8M Total Payload BAU Philosophy

Payload Size = 50,000 Lbs.	Booster		Orbiter	
Launch Operations	$334.0	11.4%	$301.6	13.2%
Launch Area Support	239.2	8.2	199.2	8.2
Training & Mission Support	13.3	0.5	13.3	0.6
AGE & Facility Maintenance	22.7	0.8	18.6	0.8
Recovery	33.4	1.1	33.4	1.5
Transportation	26.3	0.9	25.5	1.1
Tech. Support & Sustaining Engr.	24.9	0.9	19.6	0.9
Sustaining Spares	84.7	2.9	53.6	2.3
Recertification	1735.0	59.4	1294.9	56.9
Fee	239.9	8.2	188.2	8.3
Program Office Management	165.2	5.7	128.9	5.7
Total Operations	$2918.6		$2276.8	

FIGURE 4-38

TOTAL COST VS. PAYLOAD SIZE

Concept M

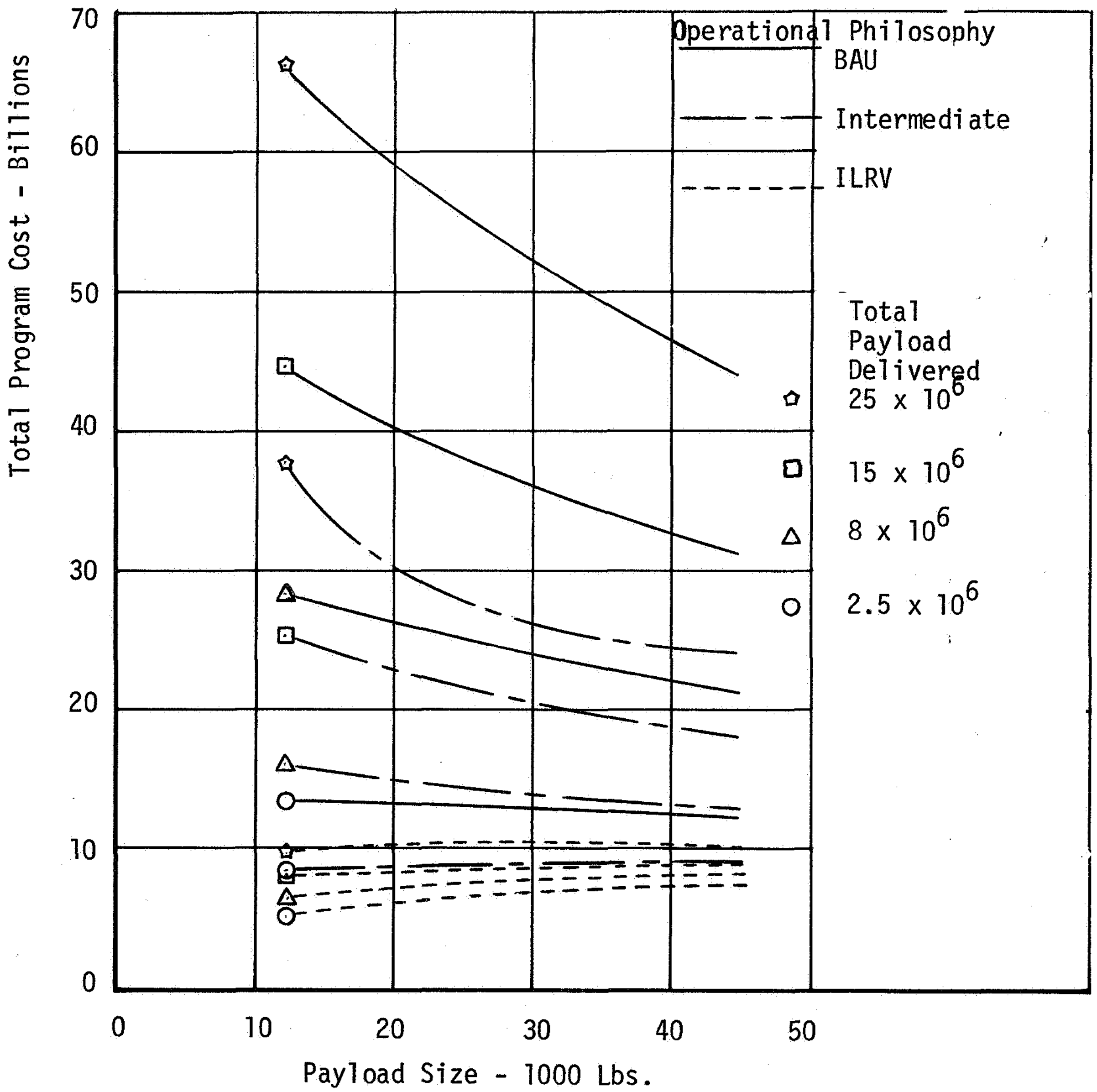


FIGURE 4-39

TOTAL PROGRAM COST VS. FLIGHTS PER YEAR

Concept M

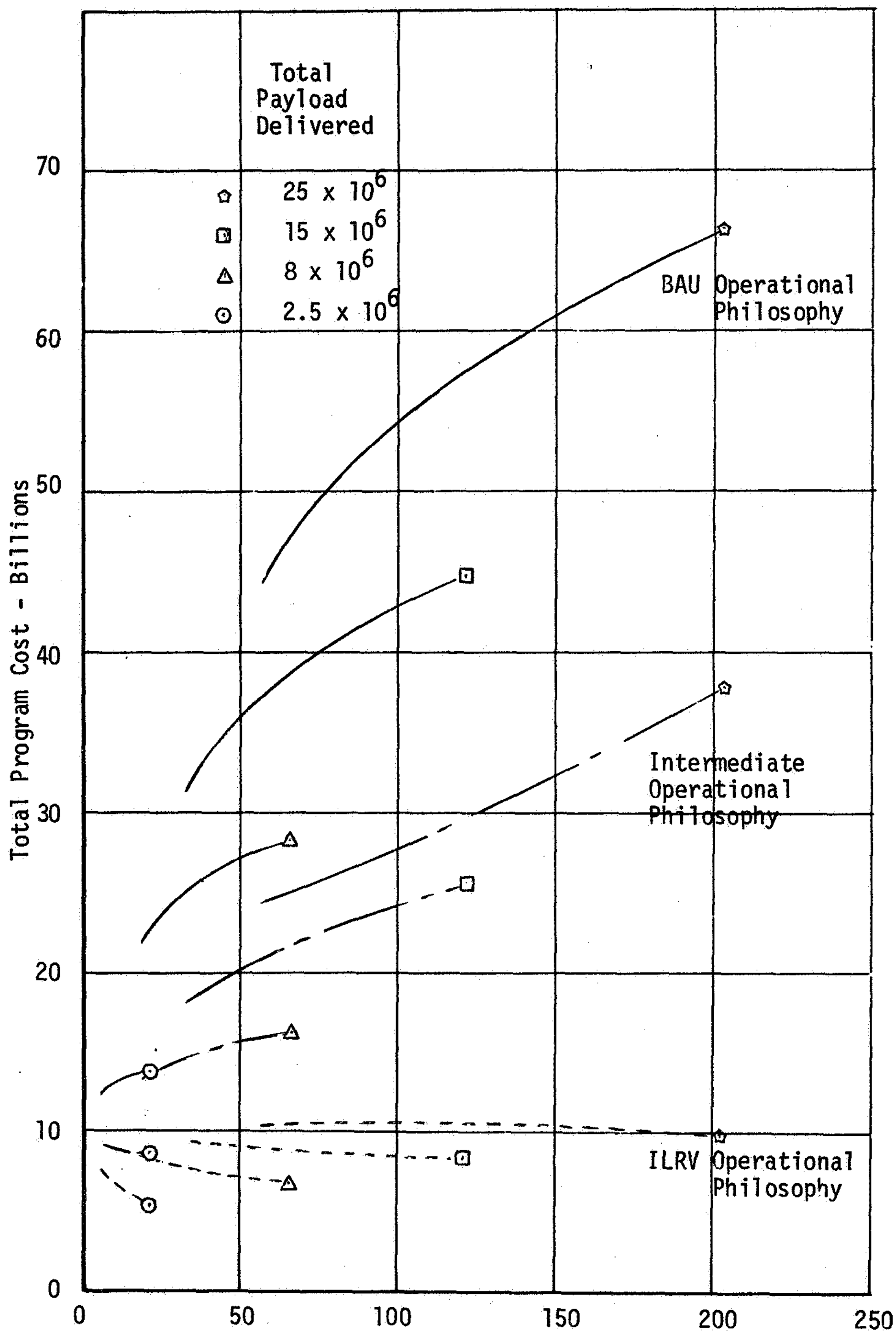


FIGURE 4-40

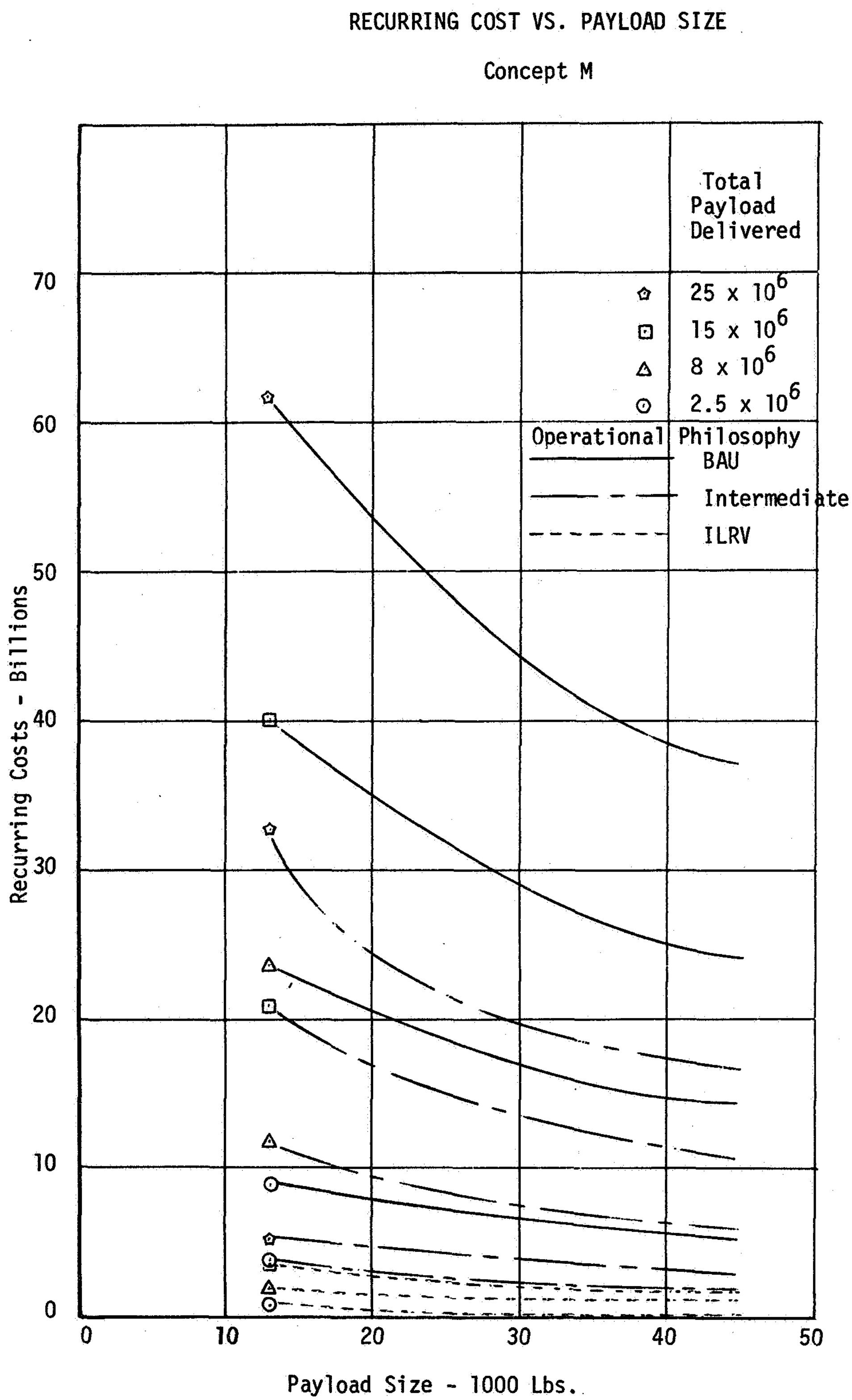

RECURRING COST VS. PAYLOAD SIZE
Concept M
Total Payload Delivered
25 x 10^6
15 x 10^6
8 x 10^6
2.5 x 10^6
Operational Philosophy
BAU
Intermediate
ILRV
Recurring Costs - Billions
0
10
20
30
40
50
60
70
Payload Size - 1000 Lbs.
0
10
20
30
40
50

FIGURE 4-41

RECURRING COST PER FLIGHT VS. FLIGHTS PER YEAR

Concept M

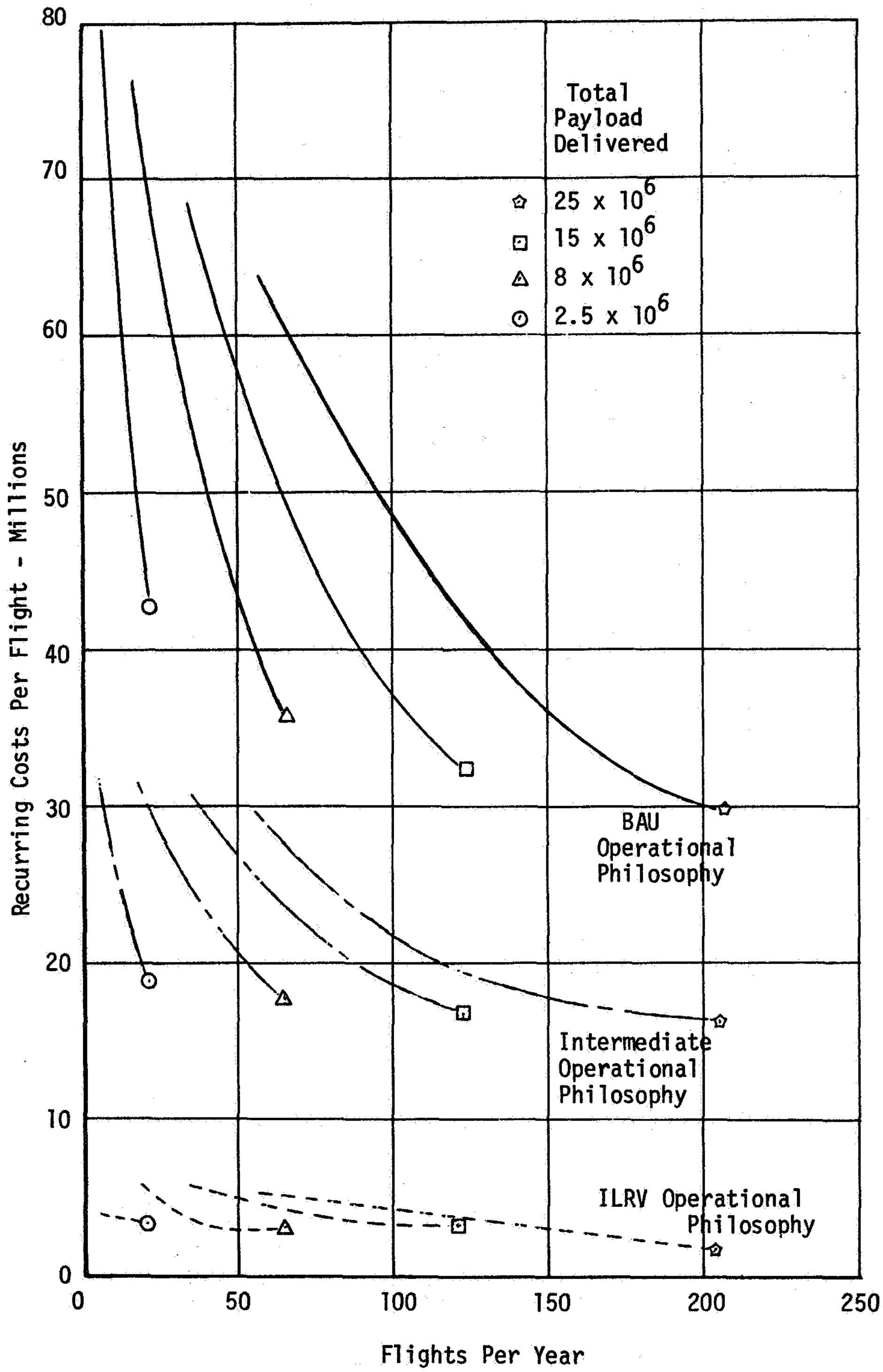


FIGURE 4-42

RECURRING COST PER FLIGHT VS. PAYLOAD SIZE

Concept M

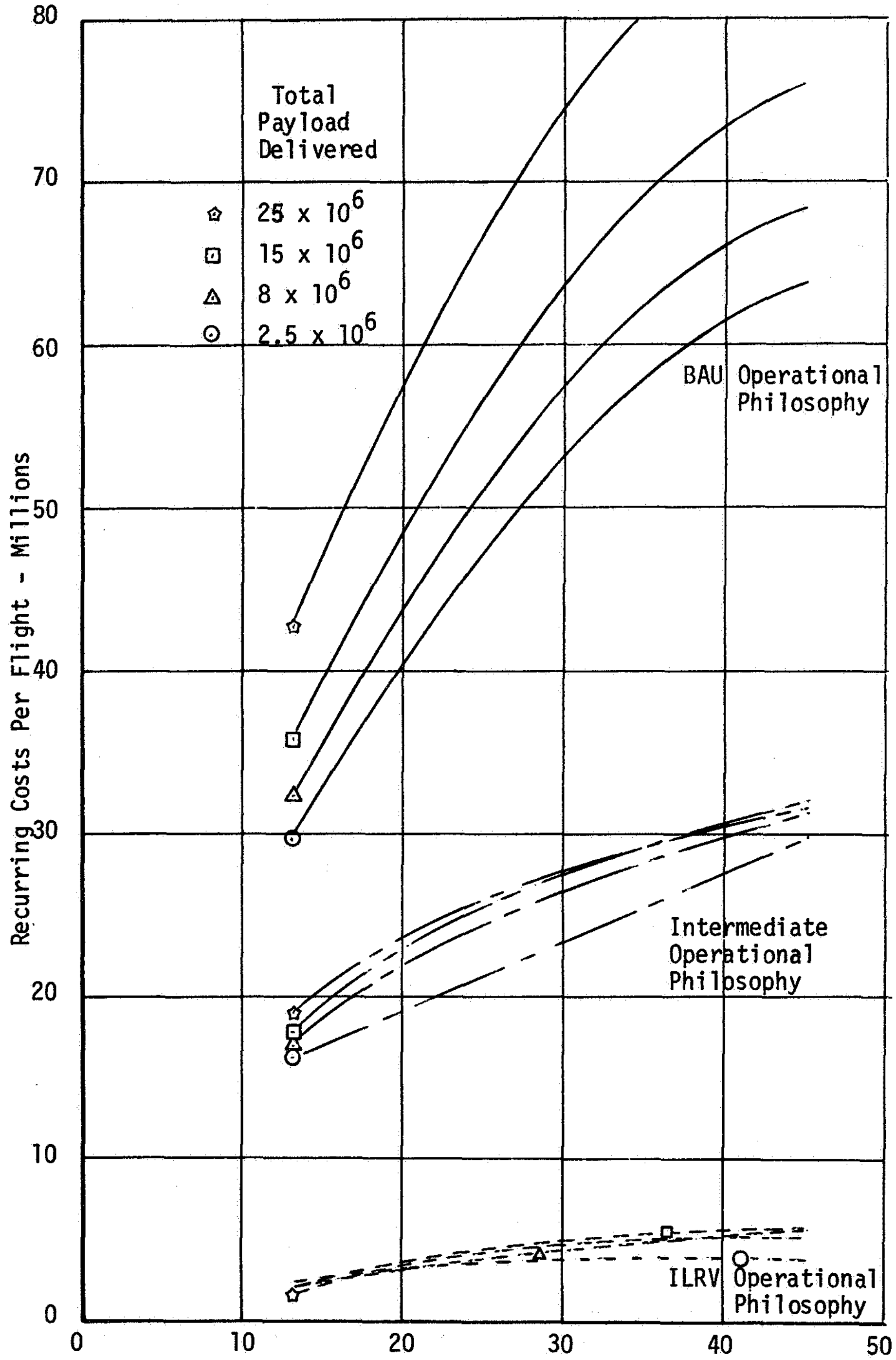


FIGURE 4-43

OPERATIONAL COST SUMMARY   MILLIONS OF 1969 DOLLARS
Concept M 8M Total Payload ILRV Philosophy

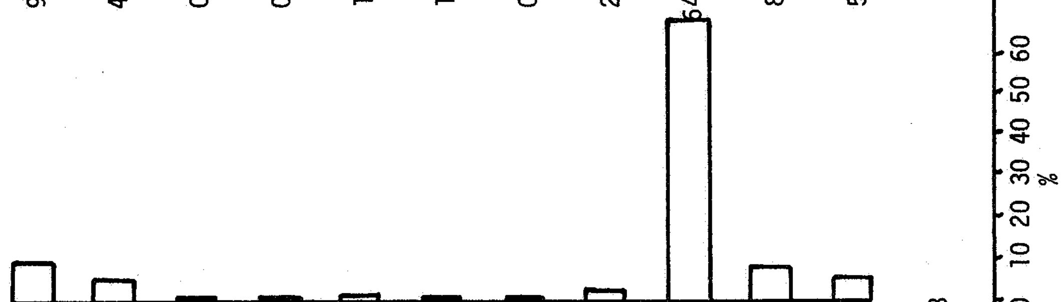
Payload Size = 45,000 Lbs.	Booster		Orbiter	
Launch Operations	$131.6	35.7%	$ 76.9	32.7%
Launch Area Support	25.8	7.0	20.7	8.8
Training & Mission Support	4.0	1.1	4.0	1.7
AGE & Facility Maintenance	4.8	1.3	3.8	1.6
Recovery	18.0	4.9	18.0	7.6
Transportation	0.3	0.1	0.3	0.1
Tech. Support & Sustaining Engr.	15.6	4.2	11.7	5.0
Sustaining Spares	31.4	8.5	16.6	7.0
Recertification	92.0	25.0	52.5	22.3
Fee	24.1	6.5	17.7	7.5
Program Office Management	20.9	5.7	13.3	5.7
Total Operations	$368.5		$235.5	

FIGURE 4-44

OPERATIONAL COST SUMMARY MILLIONS OF 1969 DOLLARS

Concept M 8M Total Payload Intermediate Philosophy

Payload Size = 45,000 Lbs.	Booster		Orbiter	
Launch Operations	$192.5	9.8%	$127.2	10.7%
Launch Area Support	95.9	4.5	76.7	6.5
Training & Mission Support	6.8	0.3	6.8	0.6
AGE & Facility Maintenance	10.5	0.5	8.4	0.7
Recovery	35.8	1.8	35.8	3.0
Transportation	26.4	1.3	26.2	2.2
Tech. Support & Sustaining Engr.	18.7	0.9	14.0	1.2
Sustaining Spares	52.7	2.6	28.0	2.4
Recertification	1277.8	64.3	698.8	59.0
Fee	159.1	8.0	95.0	8.0
Program Office Management	112.6	5.7	67.0	5.7
Total Operations	$1988.8		$1183.9	



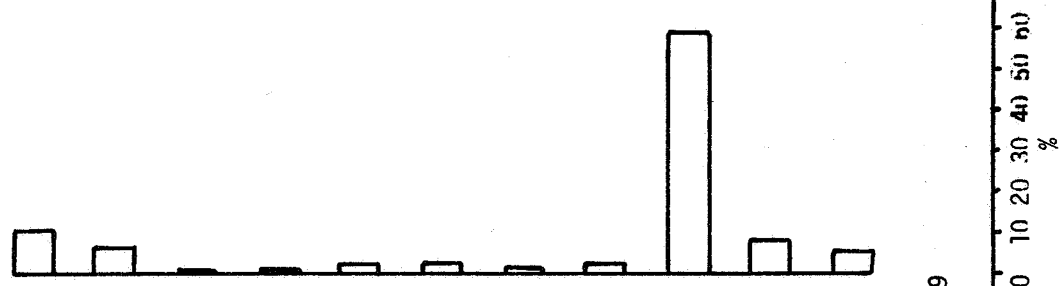


FIGURE 4-45

OPERATIONAL COST SUMMARY MILLIONS OF 1969 DOLLARS

Concept M 8M Total Payload BAU Philosophy

Payload Size = 45,000 Lbs.	Booster		Orbiter	
Launch Operations	$334.0	11.4%	$301.6	13.2%
Launch Area Support	239.2	8.2	199.2	8.7
Training & Mission Support	13.3	0.5	13.3	0.6
AGE & Facility Maintenance	22.7	0.8	18.6	0.8
Recovery	33.4	1.1	33.4	1.5
Transportation	26.3	0.9	25.5	1.1
Tech. Support & Sustaining Engr.	24.9	0.9	19.6	0.9
Sustaining Spares	84.7	2.9	53.6	2.3
Recertification	1735.0	59.4	1294.9	56.9
Fee	239.9	8.2	188.2	8.3
Program Office Management	165.2	5.7	128.9	5.7
Total Operations	$2918.6		$2276.8	

0 10 20 30 40 50 60 %   0 10 20 30 40 50 60 %

FIGURE 4-46

Comparisons of the three concepts are shown in Figures 4-49 through 4-51. In Figures 4-47 to 4-50 the total program cost trends are compared for the ILRV operational philosophy at the four total payloads delivered (or four traffic rates). As noted in the discussion of the Concept "M" data above, the inconsistency in this data is very apparent. It is more reasonable to expect the curve shape to be similar to the Concept "L" curves and at about the same total cost for a given payload size.

Figure 4-51 compares the breakdown of the total costs for each configuration and the three operational philosophies. As shown, the cost of the investment phases and operational phases are nearly equal. There is no difference in RDT&E phase costs due to the operational philosophy.

Figure 4-52 compares zero stage total costs for the three conditions studied. As expected the costs increase as the size of the zero stages increase. The zero stage for the ΔV = 18,790 case and the constant length are the same at 50,000 pounds. The ΔV = 20,890 FPS case and the constant length case have the same zero stage at the 12,500 pound payload size.

4.4.4 Cost/Weight Comparison - The relationship of estimated cost and vehicle total dry weight is demonstrated by Figures 4-53 and 4-54. General cost trends with vehicle dry weight show a reasonable correlation for each type of configuration. The data in each figure indicates the sensitivity of estimated cost to the vehicle design and the subsystem that make up each vehicle. For the RDT&E cost given in Figure 4-53 the relative lower cost for the booster is due to the ground rule of charging the orbiter with the primary development cost of all common subsystems. The RDT&E cost differential with the basic OCPDM cost line developed during Task 6 (Reference 4) is due to reduced quantities of test hardware and revised development program definition. The number of orbiters and boosters used in the development phase for the follow-on study was 2 instead of the 5 assumed in the basic OCPDM study. Ground test hardware and testing was also reduced proportionally. The basic OCPDM Task 6 costs are for the IIE configuration and are only comparable to the orbiter vehicle costs. A cost reduction of approximately 1 billion dollars is realized due to the reduced development program defined for this follow-on effort. The essential differences in the development program between the follow-on and basic study are characterized by the changes in CER's and groundrules noted previously.

Similar to the RDT&E cost, the first unit cost presented in Figure 4-54 also shows a reasonable correlation of cost and total dry weight. The cost differences are primarily due to the vehicle design and subsystems makeup. Prior OCPDM Task 6 results for the IIE configuration are comparable to the more conventional Concept "L" and "M" vehicles. The Concept "S" vehicle higher cost is primarily due to the composite structure design.

PROGRAM COST VS. PAYLOAD SIZE
2.5 M Lb. Total Payload Delivered
ILRV Operational Philosophy

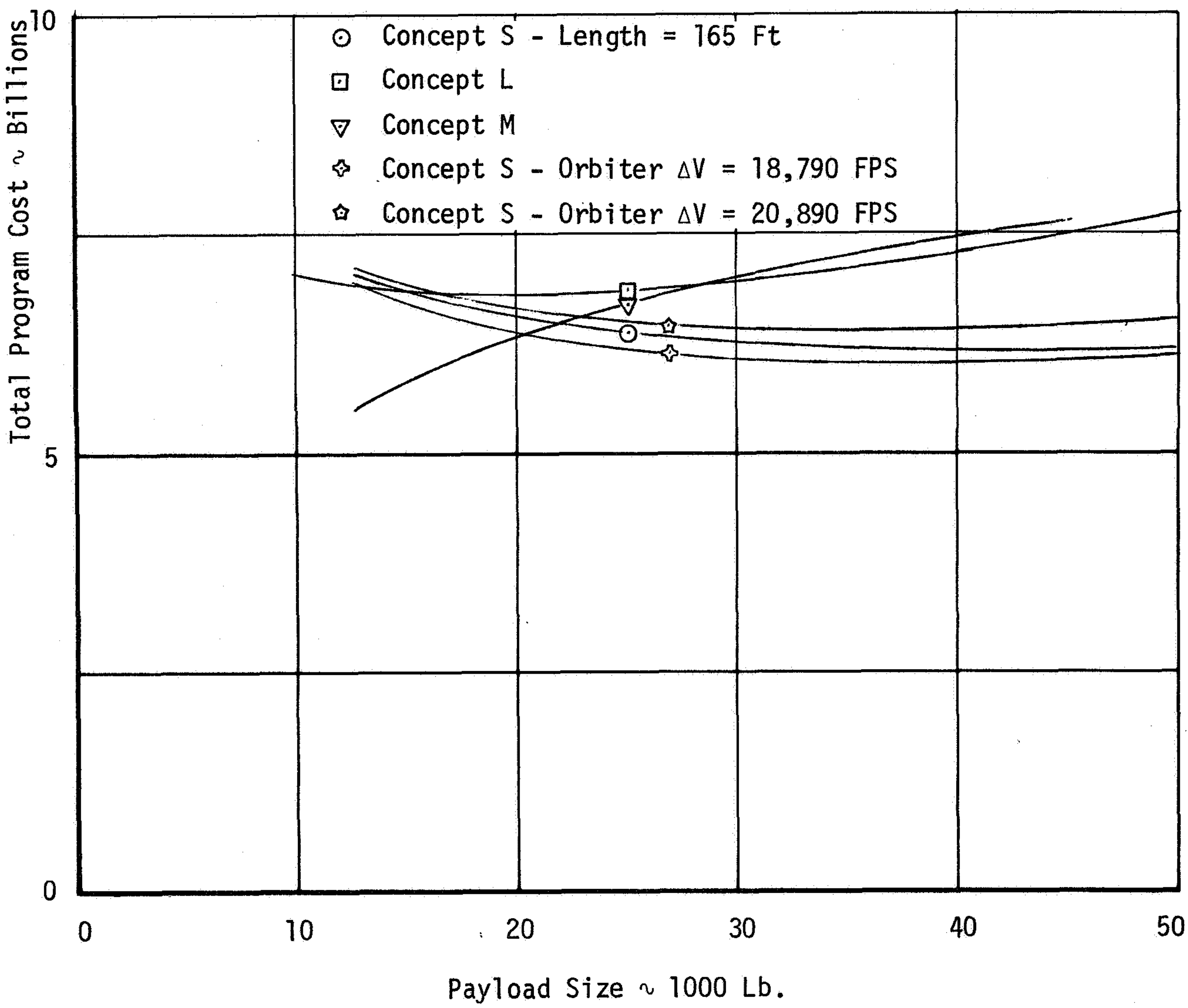


FIGURE 4-47

PROGRAM COST VS. PAYLOAD SIZE
8 M Lb. Total Payload Delivered
ILRV Operational Philosophy

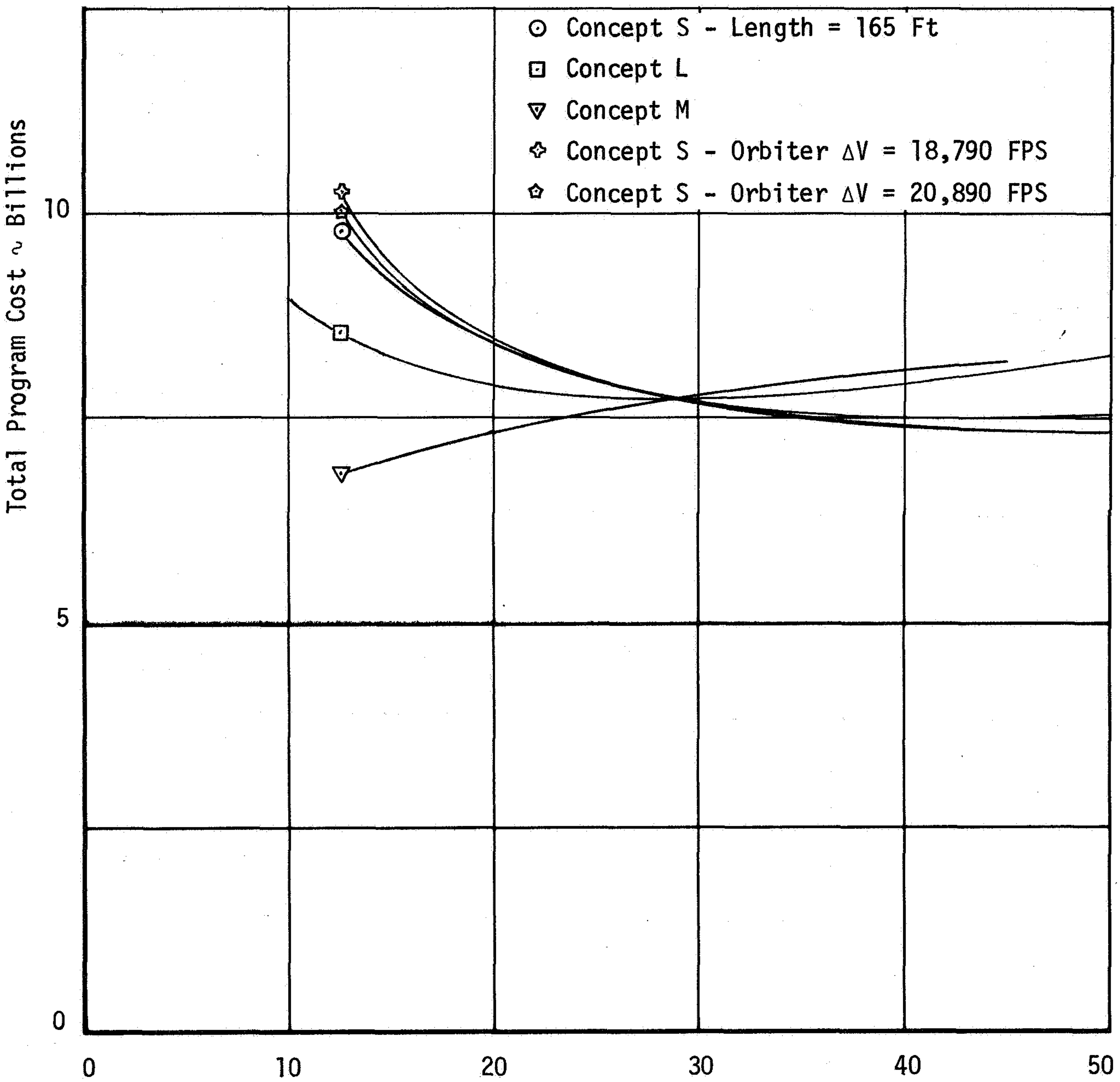


FIGURE 4-48

PROGRAM COST VS. PAYLOAD SIZE
15 M Lb. Total Payload Delivered
ILRV Operational Philosophy

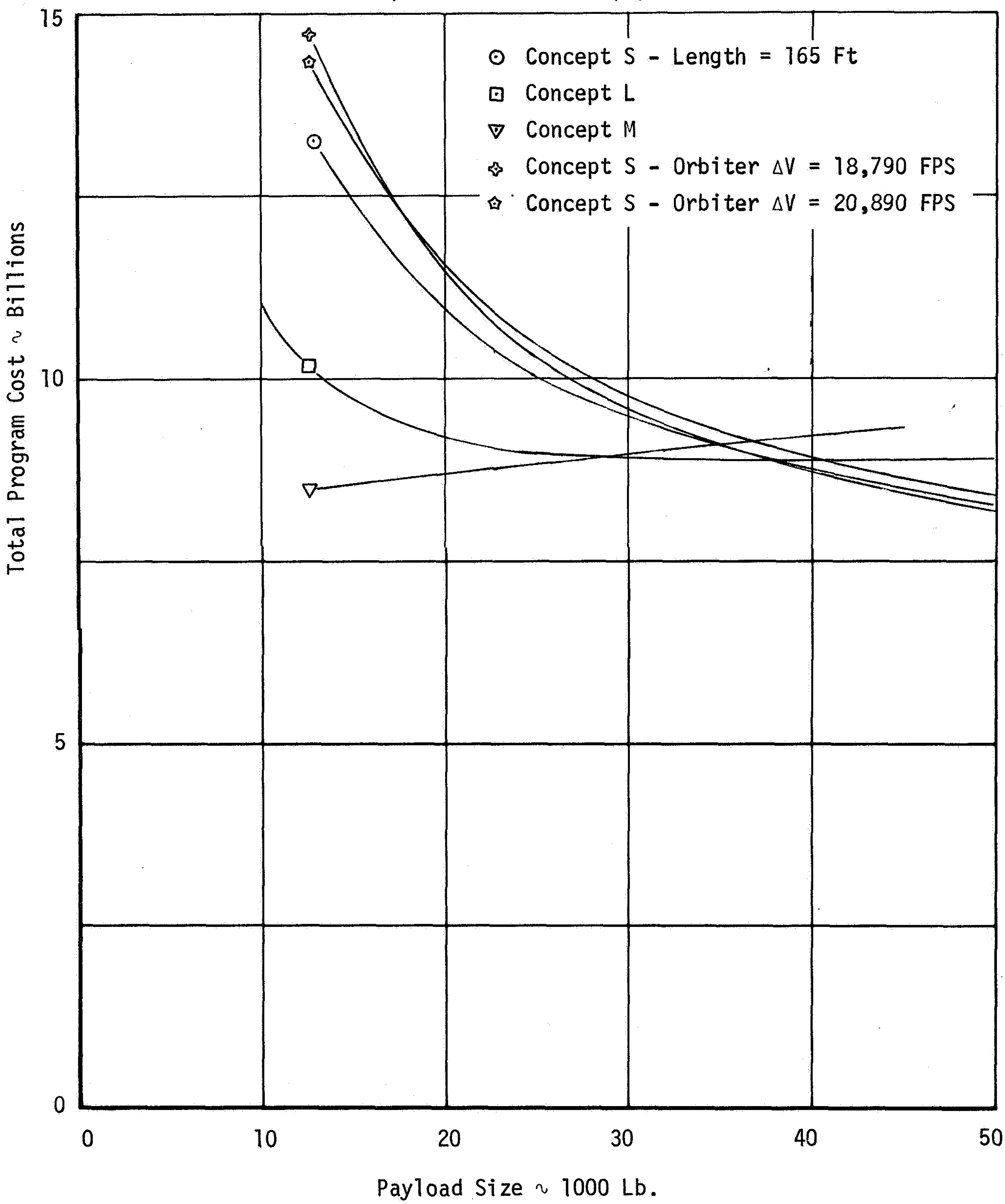


FIGURE 4-49

PROGRAM COST VS. PAYLOAD SIZE
25 M Lb. Total Payload Delivered
ILRV Operational Philosophy

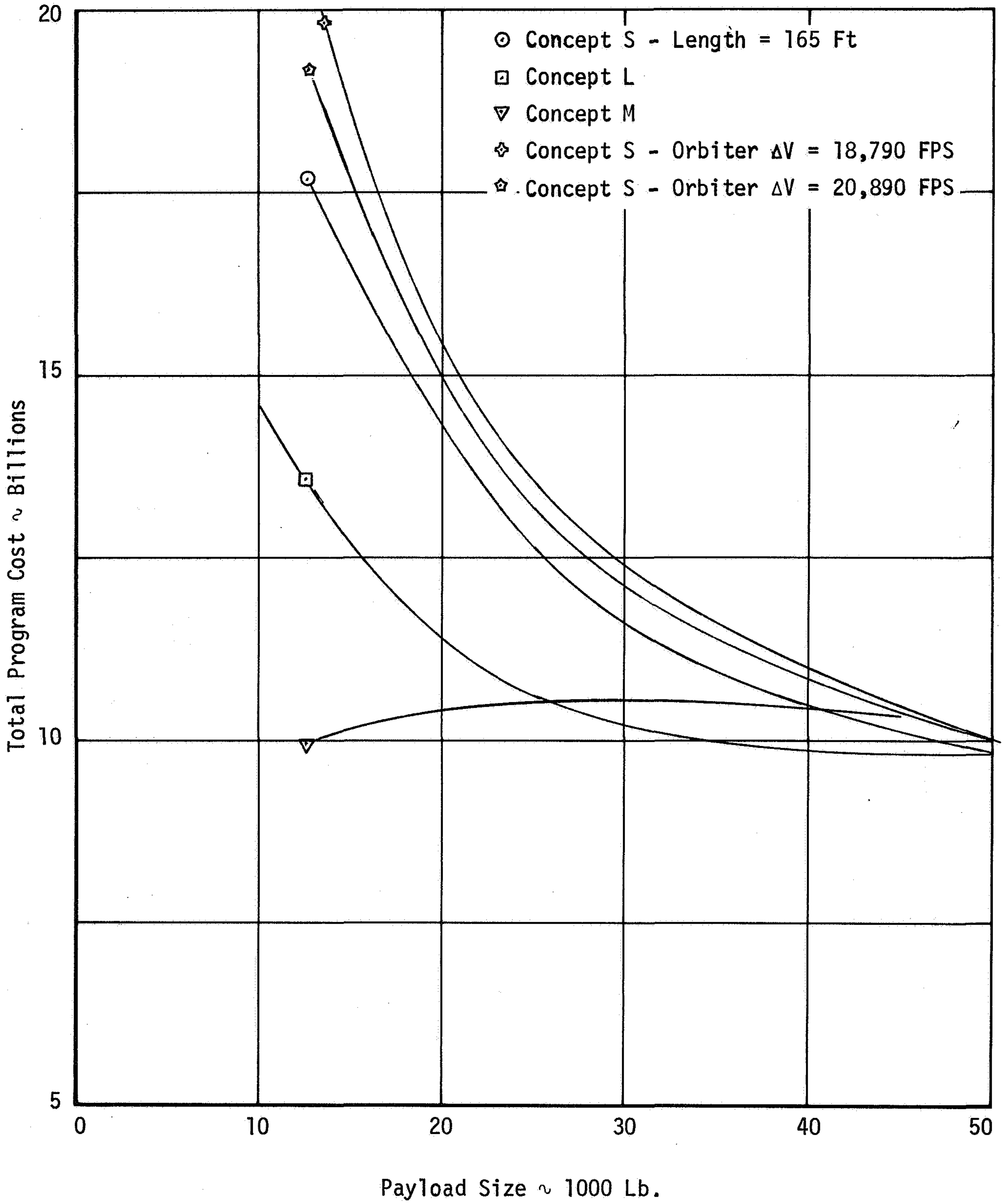


FIGURE 4-50

TOTAL COST AS A FUNCTION OF OPERATIONAL PHILOSOPHY
LARGEST PAYLOAD & 8M TOTAL PAYLOAD DELIVERED

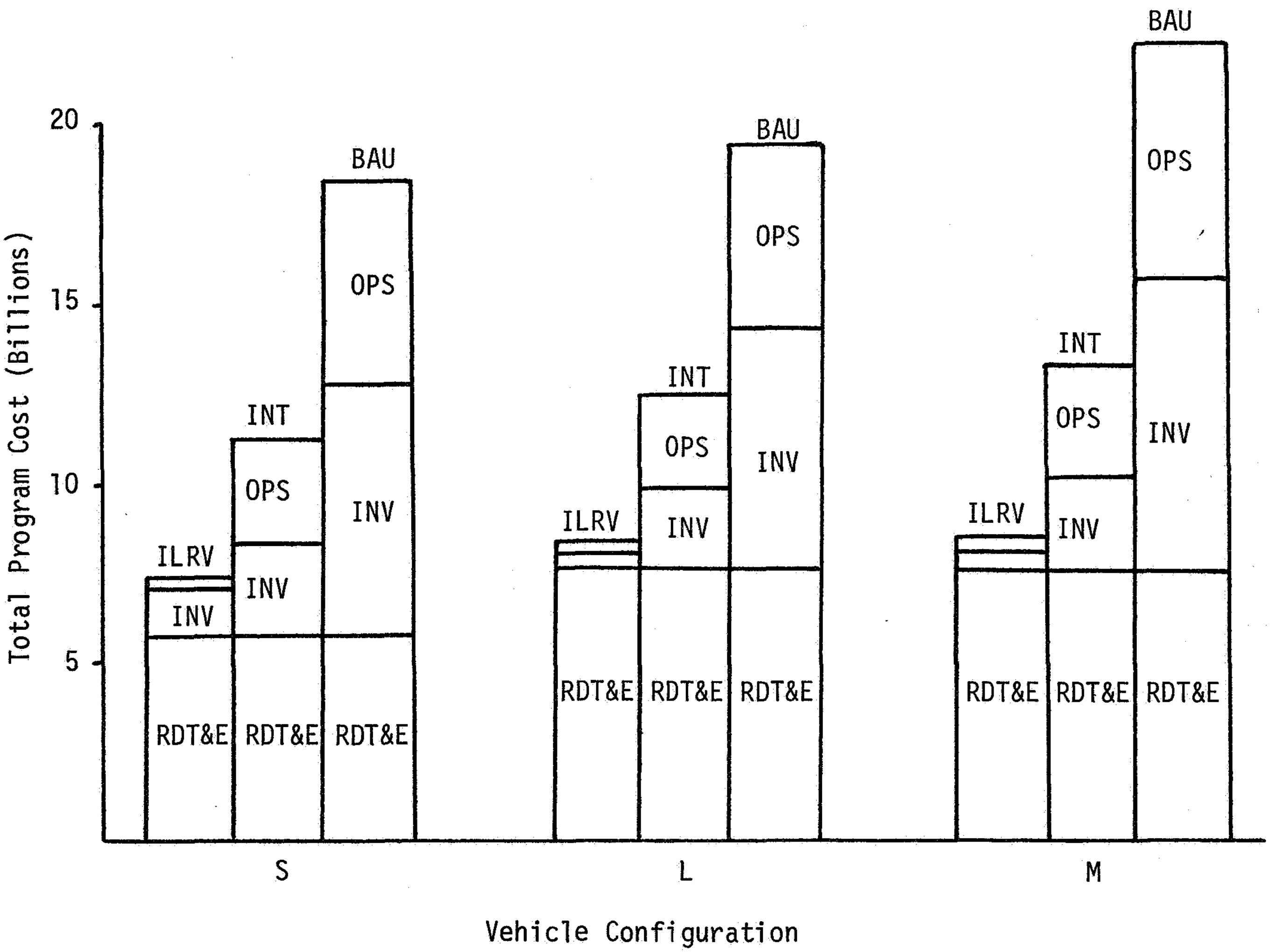


FIGURE 4-51

ZERO STAGE TOTAL COST VS. PAYLOAD SIZE
Expendable Solid Zero Stage For Concept S

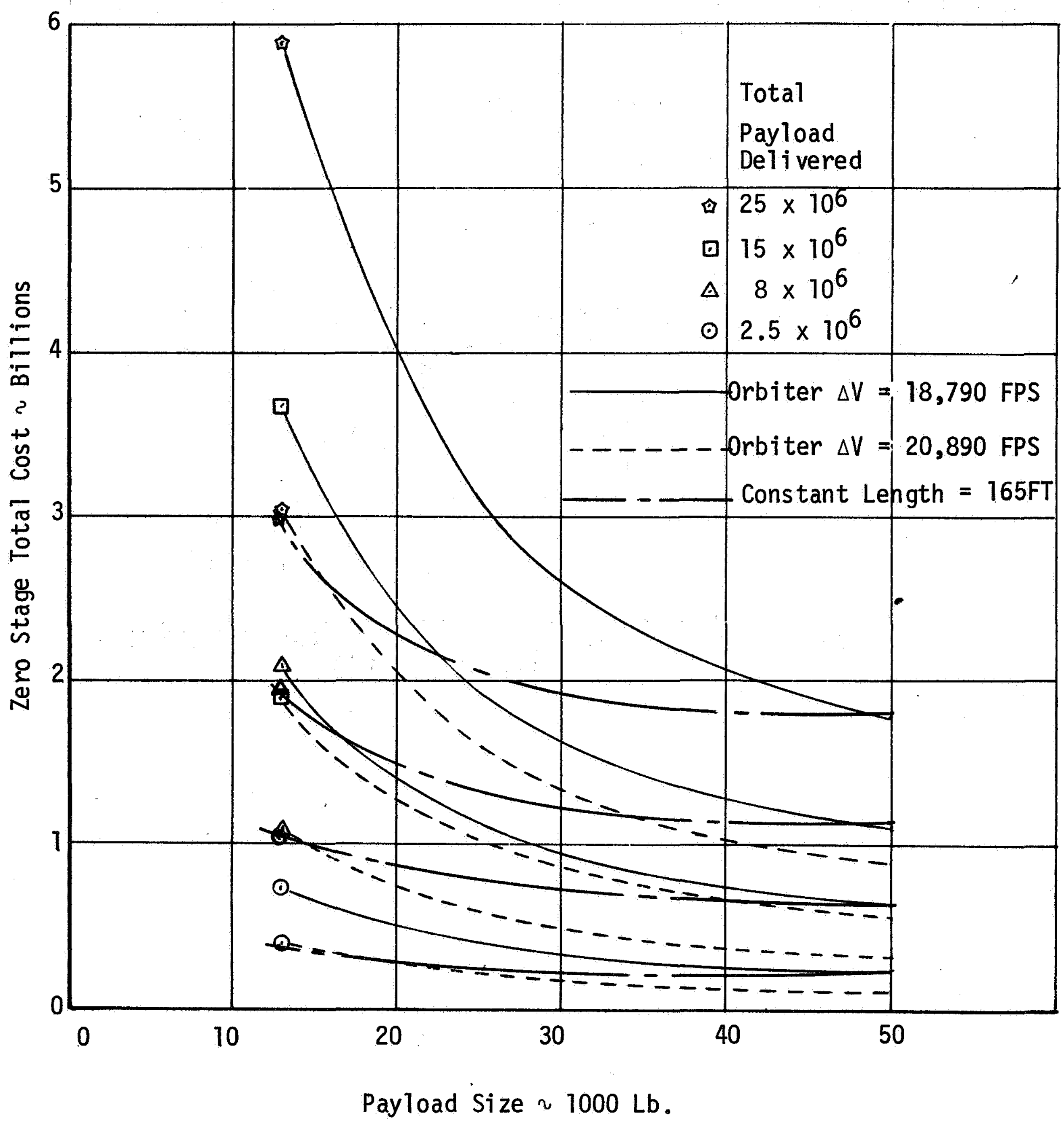


FIGURE 4-52

ORBITER AND BOOSTER RDT & E COSTS

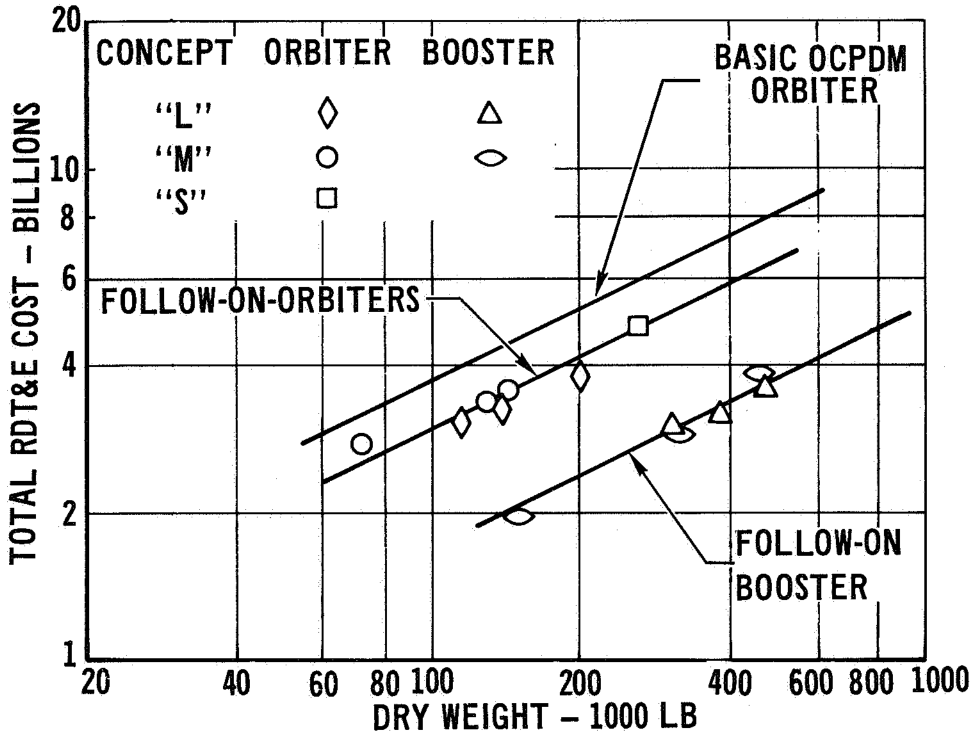


FIGURE 4-53

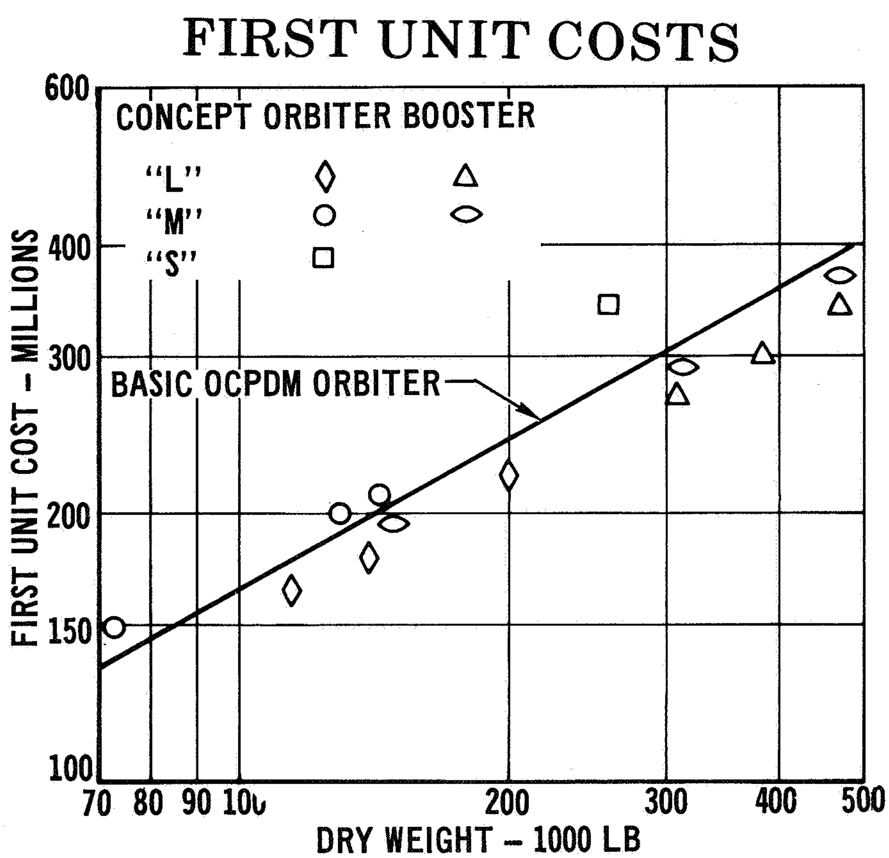

FIRST UNIT COSTS
CONCEPT ORBITER BOOSTER
"L"
"M"
"S"
BASIC OCPDM ORBITER
FIRST UNIT COST – MILLIONS
600
400
300
200
150
100
70
80
90
100
200
300
400
500
DRY WEIGHT – 1000 LB

FIGURE 4-54

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SECTION 5.0 REFERENCES

1. SAMSO TR 69-363, "Space Transportation System (STS)", Volume V Vehicle Design, dated November 1969, Confidential, Air Force Contract No. F04701-69-C-0380.
2. MDC E0049, "Integral Launch and Reentry Vehicle Systems", Volume 1, Book 1, dated November 1969, McDonnell Douglas Corporation.
3. MDC E0056, "A Two-Stage Fixed Wing Space Transportation System", Volume II, dated 15 December 1969, McDonnell Douglas Corporation.
4. G975, "Optimized Cost/Performance Design Methodology", Volume II, Book 3, dated 15 April 1969, McDonnell Douglas Corporation.
5. SAMSO TR 69-363, "Space Transportation System (STS)", Volume VII, Operations, dated November 1969, Confidential, Air Force Contract No. F04701-69-C-0380.

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APPENDIX A

DETAILED COST ESTIMATES

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A1 Concept "S" Cost Estimates - The Concept "S" configuration is a siamese configuration that was derived from the orbiter stage of the two stage vehicle developed by McDonnell Douglas for SAMSO/AFSC, under Contract F047-01-69-C-0380. For this siamese concept both of the core vehicles are identical with the additional ΔV required to achieve orbit provided by either solid or liquid zero stages. Both expendable and reuseable zero stage configurations were investigated. Three configurations were defined for each payload size and have been designated by (1) constant vehicle length of 165 ft., (2) constant orbiter ΔV of 18,790 fps and (3) constant orbiter ΔV of 20,890 fps. The constant length case is the baseline configuration. The cost estimates prepared for each configuration are presented in the following sections.

A1.1 Concept "S", Constant Vehicle Length of 165 Ft. - This is the baseline configuration of the Concept "S" vehicle and has been defined and estimated in greater detail than the other two "S" configurations. The cost estimates prepared for this configuration are presented in the following paragraphs.

A1.1.1 Total Program Cost - A total program cost summary is provided for each Concept "S" payload size in Table A-1 through A-3 for the constant length case.

A1.1.2 Orbiter/Booster Cost Summary - A total program cost summary for the Concept "S" constant length orbiter and booster portion of the cost to be added to the various combinations of zero stages is provided in Tables A-4 through A-9.

A1.1.3 Cost Summaries by Phase - The cost estimates for the orbiter and booster for the RDT&E, Investment, and Operations Phases are presented in Tables A-10 through A-36. Inventory requirements for the operational phase are shown in Figure A-1. The operational phase costs are broken down for the four traffic rates, the three operational philosophies and three payload sizes. These costs are compared on the bar chart of Figure A-2 for the three operational philosophies at three payload sizes and one traffic rate. The same costs are shown in a pie chart form in Figure A-3 and the recertification portion further broken down in Figure A-4.

A1.1.4 Zero Stage Cost - The cost estimates for the zero stages are presented in Tables A-37 through A-42. The operational phase costs for the four zero stage concepts were estimated from relationships supplied by the NASA. The solid zero stage has the propellant costs included in the investment costs while the liquid zero stages have the propellant costs included in the launch operations costs.

A1.2 Concept "S" Constant Orbiter ΔV of 18,790 FPS - For this configuration only gross cost estimates were prepared from the plot of vehicle dry weight versus cost for RDT&E and Investment. These results are presented in the following paragraphs.

A1.2.1 Total Program Cost - A total program cost summary is provided for each Concept "S" payload size in Tables A-43 through A-45 for the 18,790 fps constant ΔV case.

A1.2.2 Orbiter/Booster Cost Summary - A total program cost summary for the Concept "S" constant ΔV orbiter and booster portion of the cost to be added to the various combinations of zero stages is provided in Tables A-46 through A-48.

Detailed estimates were not prepared for the RDT&E phase or the Investment Phase.

A1.2.3 Operational Phase Cost Summary - Operational phase cost estimates are presented in Tables A-49 through A-54. These were developed for the ILRV operational philosophy only, but do cover the four traffic rates and the three payload sizes. The propellant cost for the liquid stages is included in the launch operations costs while the propellant costs for the solid stages are included in the investment costs.

A1.2.4 Zero Stage Cost - The cost estimates for the zero stages are presented in Tables A-55 through A-60.

A1.3 Concept "S", Constant Orbiter ΔV of 20,890 fps - For this configuration only gross cost estimates were prepared from the plot of vehicle dry weight versus cost for RDT&E and Investment. These results are presented in the following paragraphs.

A1.3.1 Total Program Cost - A total program cost summary is provided for each Concept "S" payload size in Tables A-61 through A-63 for the 20,890 fps constant ΔV case.

A1.3.2 Orbiter/Booster Cost Summary - A total program cost summary for the Concept "S" constant ΔV orbiter and booster portion of the cost to be added to the various combinations of zero stages is provided in Tables A-64 through A-66. Detailed estimates were not prepared for the RDT&E phase or the Investment phase.

A1.3.3 Operational Phase Cost Summary - Operational phase cost estimates are presented in Tables A-67 through A-72.

A1.3.4 Zero Stage Cost - The cost estimates for the zero stage are presented in Tables A-73 through A-78.

INVENTORY REQUIREMENTS

Concept S - Booster or Orbiter

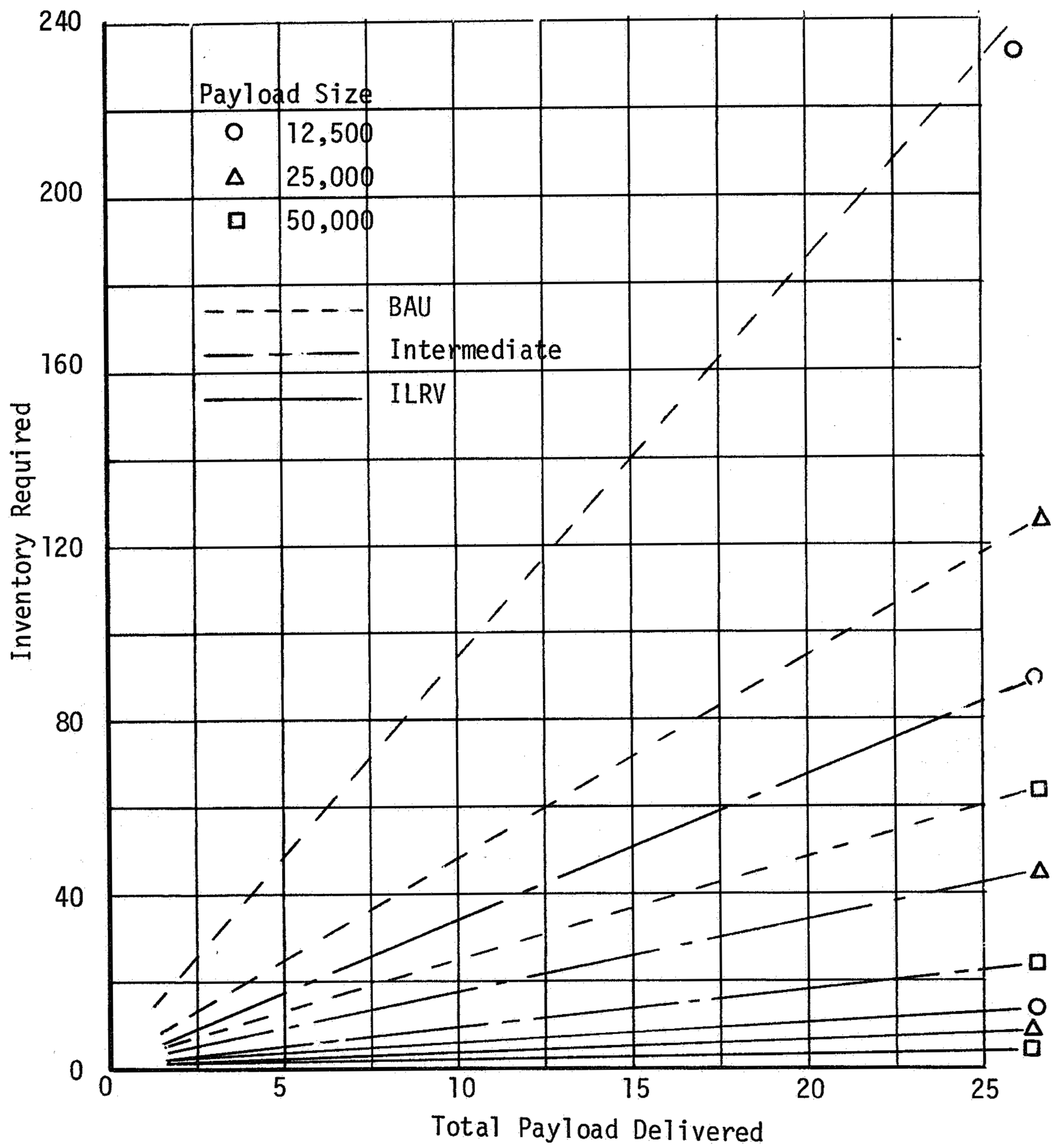


FIGURE A-1

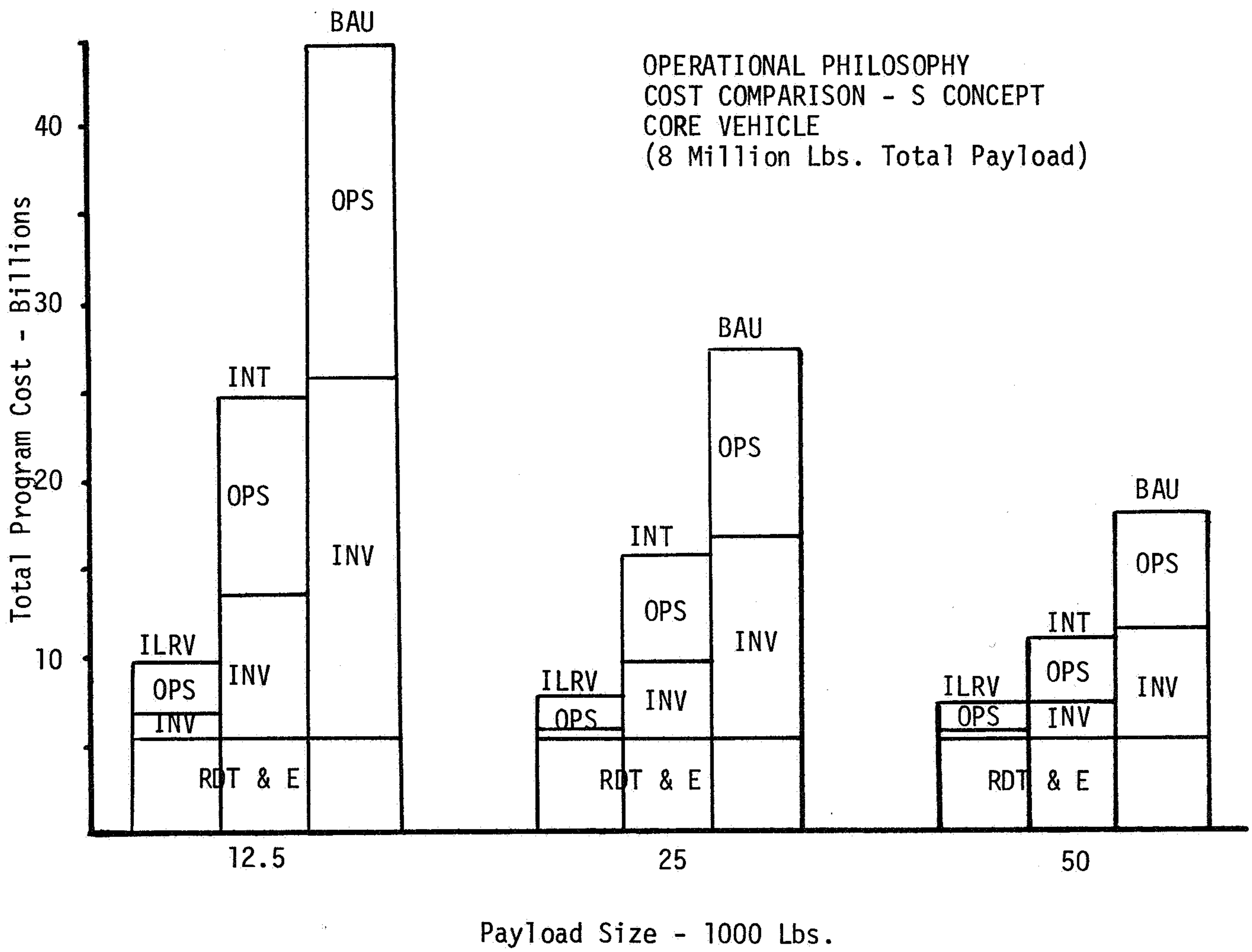
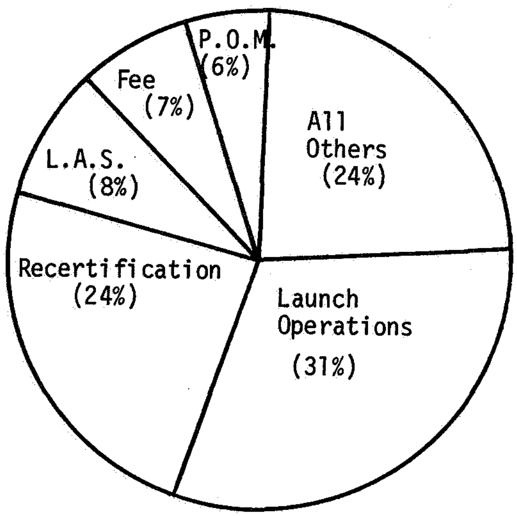

OPERATIONAL PHILOSOPHY
COST COMPARISON - S CONCEPT
CORE VEHICLE
(8 Million Lbs. Total Payload)
Total Program Cost - Billions
40
30
20
10
BAU
INT
ILRV
OPS
INV
RDT & E
12.5
25
50
Payload Size - 1000 Lbs.

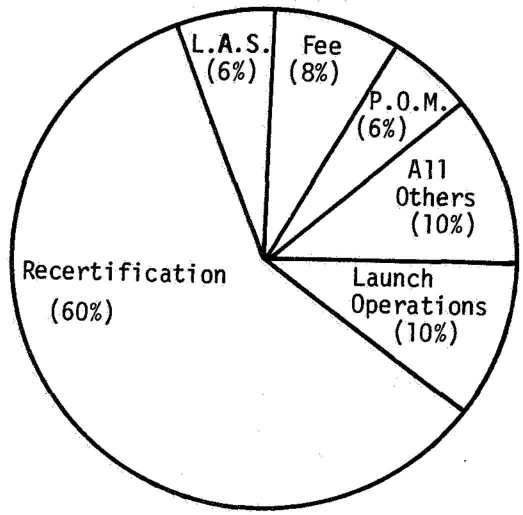
FIGURE A-2

CONCEPT "S" CORE VEHICLE
OPERATIONAL COST BREAKDOWN
(50K Payload, 8 Million Lbs. Total Cargo Wgt.)

ILRV



Intermediate



OCPDM

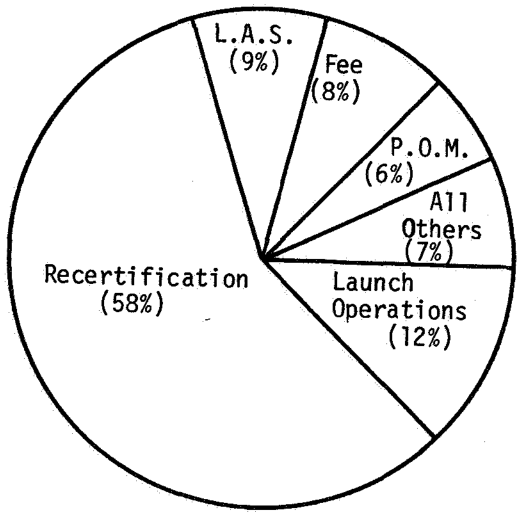


FIGURE A-3

CONCEPT S CORE VEHICLE
RECERTIFICATION COST
BREAKDOWN BY PHILOSOPHY
AND PAYLOAD SIZE

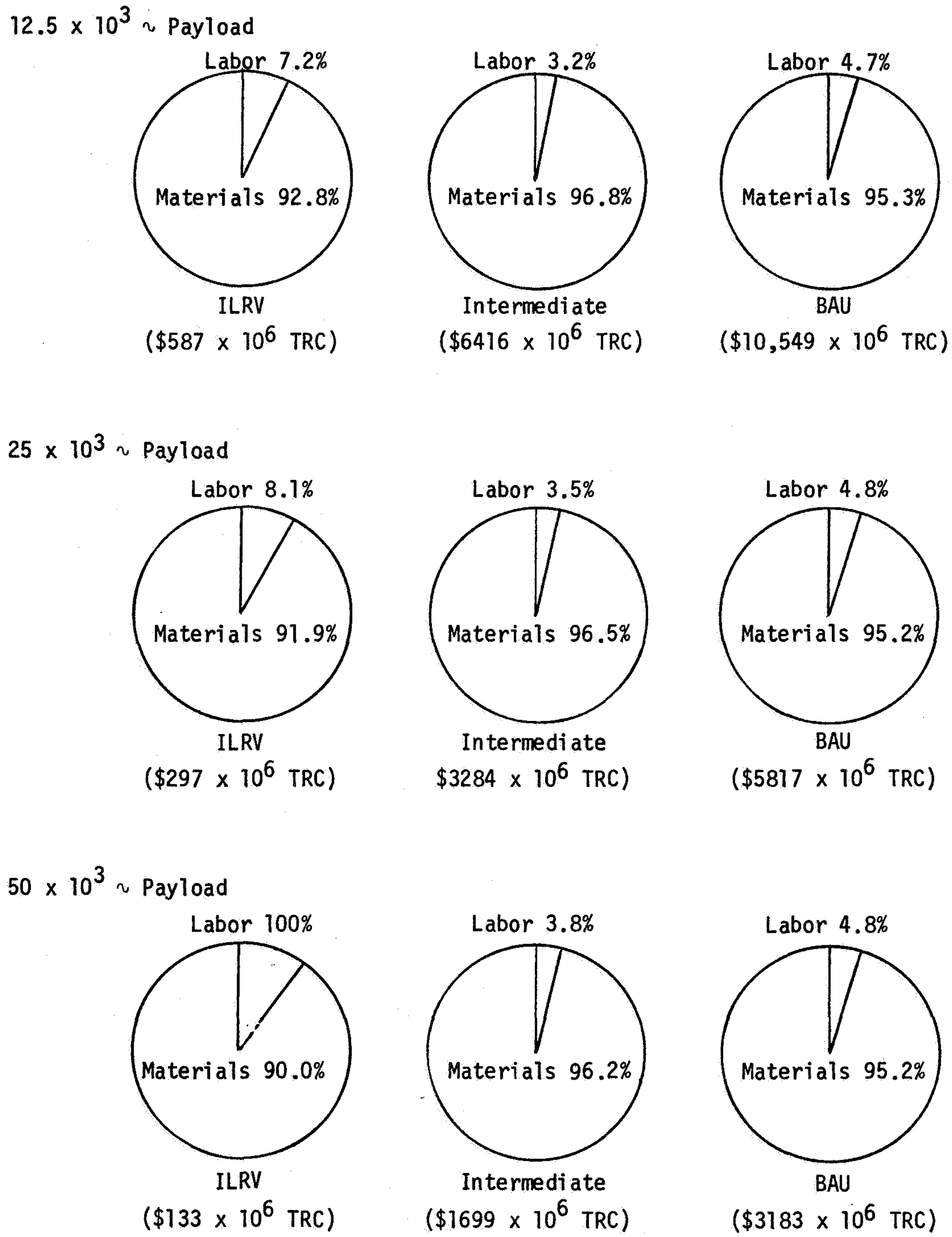


FIGURE A-4

Table A-1
Total Program Cost Summary
12.5 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY, CONSTANT LENGTH=165 FT	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload = 2.5 Million Lb.				
Total Orbiter and Booster Cost	6,762	6,762	6,762	6,762
Total Zero Stage Cost	1,790	371	661	583
Total Program Cost	8,552	7,133	7,423	7,345
Total Payload = 8.0 Million Lb.				
Total Orbiter and Booster Cost	8,772	8,772	8,772	8,772
Total Zero Stage Cost	4,928	1,054	1,553	1,499
Total Program Cost	13,700	9,826	10,325	10,271
Total Payload = 15 Million Lb.				
Total Orbiter and Booster Cost	11,420	11,420	11,420	11,420
Total Zero Stage Cost	8,660	1,866	2,594	2,539
Total Program Cost	20,080	13,286	14,014	13,959
Total Payload = 25 Million Lb.				
Total Orbiter and Booster Cost	15,078	15,078	15,078	15,078
Total Zero Stage Cost	13,759	2,975	3,974	3,914
Total Program Cost	28,837	18,053	19,052	18,992

Table A-2
Total Program Cost Summary
25 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY, CONSTANT LENGTH=165 FT	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload = 2.5 Million Lb.				
Total Orbiter and Booster Cost	6,119	6,119	6,119	6,119
Total Zero Stage Cost	1,132	259	473	389
Total Program Cost	7,251	6,378	6,592	6,508
Total Payload = 8.0 Million Lb.				
Total Orbiter and Booster Cost	7,155	7,155	7,155	7,155
Total Zero Stage Cost	2,996	756	1,020	971
Total Program Cost	10,151	7,911	8,175	8,126
Total Payload = 15 Million Lb.				
Total Orbiter and Booster Cost	8,719	8,719	8,719	8,719
Total Zero Stage Cost	4,765	1,280	1,635	1,626
Total Program Cost	13,484	9,999	10,354	10,345
Total Payload = 25 Million Lb.				
Total Orbiter and Booster Cost	10,639	10,639	10,639	10,639
Total Zero Stage Cost	8,232	2,037	2,472	2,495
Total Program Cost	18,871	12,676	13,111	13,134

Table A-3
Total Program Cost Summary
50 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY, CONSTANT LENGTH=165 FT	EXPENDABLE LIQUID	EXPENDABLE SOLID	REUSABLE LIQUID	REUSABLE SOLID
Total Payload = 2.5 Million Lb.				
Total Orbiter and Booster Cost	5,922	5,922	5,922	5,922
Total Zero Stage Cost	851	240	413	309
Total Program Cost	6,773	6,162	6,335	6,231
Total Payload = 8.0 Million Lb.				
Total Orbiter and Booster Cost	6,705	6,705	6,705	6,705
Total Zero Stage Cost	2,077	643	781	749
Total Program Cost	8,782	7,348	7,486	7,454
Total Payload = 15 Million Lb.				
Total Orbiter and Booster Cost	7,123	7,123	7,123	7,123
Total Zero Stage Cost	3,102	1,127	1,185	1,239
Total Program Cost	10,225	8,250	8,308	4,362
Total Payload = 25 Million Lb.				
Total Orbiter and Booster Cost	8,080	8,080	8,080	8,080
Total Zero Stage Cost	5,555	1,790	1,739	1,889
Total Program Cost	14,635	9,870	9,819	9,969

Table A-4
Orbiter/Booster Cost Summary
12.5 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Total Payload Weight = 2.5 Million Lb			
ILRV Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	218	218	436
Operational Phase	325	309	634
Total Program Cost	5275	1487	6762
Intermediate Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	1330	1331	2661
Operational Phase	1696	1676	3372
Total Program Cost	7758	3967	11725
Current Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Invesement Phase	3768	3772	7540
Operational Phase	3312	3257	6569
Total Program Cost	11812	7989	19801
Total Payload Weight = 8.0 Million Lb			
ILRV Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	618	618	1236
Operational Phase	934	910	1844
Total Program Cost	6284	2488	8772
Intermediate Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	4047	4051	8098
Operational Phase	4967	4928	9895
Total Program Cost	13746	9939	23685
Current Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	10186	10193	20379
Operational Phase	8735	8621	17356
Total Program Cost	23653	19774	43427

Table A-5
Orbiter/Booster Cost Summary
12.5 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Total Payload Weight = 15 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	1158	1158	2316
Operational Phase	1720	1692	3412
Total Program Cost	7610	3810	11420
Intermediate Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	7062	7067	14129
Operational Phase	8984	8931	17915
Total Program Cost	20778	16958	37736
Current Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Invesement Phase	17215	17228	34443
Operational Phase	14866	14700	29566
Total Program Cost	36813	32888	69701
Total Payload Weight = 25 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	1998	1818	3816
Operational Phase	2836	2734	5570
Total Program Cost	9566	5512	15078
Intermediate Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	10757	10902	21659
Operational Phase	14721	14767	29488
Total Program Cost	30210	26629	56839
Current Operational Philosophy			
Contract Definition Phase	31	4	35
RDT & E Phase	4701	956	5657
Investment Phase	26348	26254	52602
Operational Phase	22994	22778	45772
Total Program Cost	54074	49992	104066

Table A-6
Orbiter/Booster Cost Summary
25 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Total Payload Weight= 2.5 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	0	0	
Operational Phase	212	201	413
Total Program Cost	4956	1163	6119
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	618	619	1237
Operational Phase	913	901	1814
Total Program Cost	6275	2482	8757
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Invesement Phase	1987	1990	3977
Operational Phase	1893	1859	3752
Total Program Cost	8624	4811	13435
Total Payload Weight = 8 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	218	218	436
Operational Phase	516	497	1013
Total Program Cost	5478	1677	7155
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	2148	2152	4300
Operational Phase	2619	2594	5203
Total Program Cost	9511	5708	15219
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	5669	5677	11346
Operational Phase	4895	4824	9719
Total Program Cost	15308	11463	26771

Table A-7
Orbiter/Booster Cost Summary
25 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Total Payload Weight = 15 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	619	620	1239
Operational Phase	897	877	1774
Total Program Cost	6260	2459	8719
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	3763	3933	7696
Operational Phase	4661	4598	9259
Total Program Cost	13168	9493	22661
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Invesement Phase	9747	9621	19368
Operational Phase	8281	8185	16466
Total Program Cost	22772	18768	41540
Total Payload Weight = 25 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	984	986	1970
Operational Phase	1492	1471	2963
Total Program Cost	7220	3419	10639
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	6059	6069	12128
Operational Phase	7639	7596	15235
Total Program Cost	18442	14627	33069
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4710	958	5668
Investment Phase	14909	14812	29721
Operational Phase	12739	12606	25345
Total Program Cost	32392	28380	60772

Table A-8
Orbiter/Booster Cost Summary
50 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Total Payload Weight = 2.5 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	0	0	0
Operational Phase	108	101	209
Total Program Cost	4857	1065	5922
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	218	219	437
Operational Phase	515	508	1023
Total Program Cost	5482	1691	7173
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Invesement Phase	987	991	1978
Operational Phase	1095	1075	2170
Total Program Cost	6831	3030	9861
Total Payload Weight = 8.0 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	218	219	437
Operational Phase	283	272	555
Total Program Cost	5250	1455	6705
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	987	991	1978
Operational Phase	1412	1398	2810
Total Program Cost	7148	3353	10501
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	3211	3224	6435
Operational Phase	2767	2725	5492
Total Program Cost	10727	6913	17640

Table A-9
Orbiter/Booster Cost Summary
50 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Total Payload Weight = 15 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	218	219	437
Operational Phase	493	480	973
Total Program Cost	5460	1663	7123
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	1993	2002	3995
Operational Phase	2476	2457	4933
Total Program Cost	9218	5423	14641
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Invesement Phase	5424	5447	10871
Operational Phase	4646	4583	9229
Total Program Cost	14819	10994	25813
Total Payload Weight = 25 Million Lb.			
ILRV Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	422	424	846
Operational Phase	767	754	1521
Total Program Cost	5938	2142	8080
Intermediate Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	3211	3224	6435
Operational Phase	3997	3974	7971
Total Program Cost	11957	8162	20119
Current Operational Philosophy			
Contract Definition Phase	34	4	38
RDT & E Phase	4715	960	5675
Investment Phase	8329	8366	16695
Operational Phase	7131	7047	14178
Total Program Cost	20209	16377	36586

Table A-10
RDT&E, Contract Definition Phase Cost Summary
12.5 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	22	3	25
Project Management	2		2
Subtotal	24	3	27
Fee	2		2
Subtotal	26	3	29
Program Office Management	5	1	6
Total Contract Definition	31	4	35
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	650		650
Power Supply	77		77
ECLS	34		34
Avionics	446		446
Propulsion			
Jet	136		136
Orbit Maneuver	48		48
Attitude Control	130		130
Main Boost	715		715
Drop-in Tank	10	12	22
Total Propulsion	1039	12	1051
Total Subsystems D&D	2246	12	2258
AGE & Special Test Equipment	279	157	436
Launch Facilities	30	20	50
Trainers & Simulators	152		152
System Integration			
System Engineering	165	4	169
Wind Tunnel Test	23		23
Static Fire Test	67		67
Ground Test Hardware	401	2	403
Flight Test Hardware	506	507	1013
Flight Test Hardware Spares	34	34	68
Mockups	27		27
Horizontal Flight Testing	29		29
Vertical Flight Testing	115	75	190
Refurbishment	107	46	153
Total System Integration	1474	668	2142
Total Basic RDT&E	4181	857	5038
Project Management	50	4	54
Subtotal	4231	861	5092
Fee	423	86	509
Subtotal	4654	947	5601
Program Office Management	47	9	56
Total RDT&E Phase	4701	956	5657

Table A-11
RDT&E, Contract Definition Phase Cost Summary
25 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	23	3	26
Project Management	2		2
Subtotal	25	3	28
Fee	3		3
Subtotal	28	3	31
Program Office Management	6	1	7
Total Contract Definition	34	4	38
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	651		651
Power Supply	77		77
ECLS	34		34
Avionics	446		446
Propulsion			
Jet	141		141
Orbit Maneuver	49		49
Attitude Control	132		132
Main Boost	715		715
Drop-in Tank	8	12	20
Total Propulsion	1045	12	1057
Total Subsystems D&D	2253	12	2265
AGE & Special Test Equipment	279	157	436
Launch Facilities	30	20	50
Trainers & Simulators	152		152
System Integration			
System Engineering	165	4	169
Wind Tunnel Test	23		23
Static Fire Test	67		67
Ground Test Hardware	401	2	403
Flight Test Hardware	507	508	1015
Flight Test Hardware Spares	34	34	68
Mockups	27		27
Horizontal Flight Testing	29		29
Vertical Flight Testing	115	75	190
Refurbishment	107	46	153
Total System Integration	1475	669	2144
Total Basic RDT&E	4189	858	5047
Project Management	50	4	54
Subtotal	4239	862	5101
Fee	424	86	510
Subtotal	4663	948	5611
Program Office Management	47	10	57
Total RDT&E Phase	4710	958	5668

Table A-12
RDT&E, Contract Definition Phase Cost Summary
50 K Concept "S" (Millions of 1969 Dollars)

CONSTANT LENGTH = 165 FT.	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	23	3	26
Project Management	2		2
Subtotal	25	3	28
Fee	3		3
Subtotal	28	3	31
Program Office Management	6	1	7
Total Contract Definition	34	4	38
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	653		653
Power Supply	77		77
ECLS	34		34
Avionics	446		446
Propulsion			
Jet	149		149
Orbit Maneuver	50		50
Attitude Control	134		134
Main Boost	715		715
Drop-in Tank		12	12
Total Propulsion	1048	12	1060
Total Subsystems D&D	2258	12	2270
AGE & Special Test Equipment	279	157	436
Launch Facilities	30	20	50
Trainers & Simulators	152		152
System Integration			
System Engineering	165	4	169
Wind Tunnel Test	23		23
Static Fire Test	67		67
Ground Test Hardware	402	2	404
Flight Test Hardware	506	510	1016
Flight Test Hardware Spares	34	34	68
Mockups	27		27
Horizontal Flight Testing	29		29
Vertical Flight Testing	115	75	190
Refurbishment	107	46	153
Total System Integration	1475	671	2146
Total Basic RDT&E	4194	860	5054
Project Management	50	4	54
Subtotal	4244	864	5108
Fee	424	86	510
Subtotal	4668	950	5618
Program Office Management	47	10	57
Total RDT&E Phase	4715	960	5675

Table A-13
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5K Concept "S", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	99	99	198
Power Supply	6	6	12
ECLS	2	2	4
Avionics	15	15	30
Propulsion	29	29	58
Drop-in Tank	1	1	2
Final Assembly & Checkout	13	13	26
Sustaining Engineering	13	13	26
Sustaining Tooling	10	10	20
Initial Spares	7	7	14
Project Management	1	1	2
Fee	20	20	40
Total	216	216	432
Program Office Management	2	2	4
Total Cost	218	218	436
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	610	610	1220
Power Supply	38	38	76
ECLS	11	11	22
Avionics	93	93	186
Propulsion	188	188	376
Drop-in Tank	4	5	9
Final Assembly & Checkout	78	78	156
Sustaining Engineering	67	67	134
Sustaining Tooling	55	55	110
Initial Spares	46	46	92
Project Management	7	7	14
Fee	120	120	240
Total	1317	1318	2635
Program Office Management	13	13	26
Total Cost	1330	1331	2661
Quantity of Vehicles	7	7	14
Current Philosophy			
Thermal/Structure	1744	1744	3488
Power Supply	108	108	216
ECLS	31	31	62
Avionics	270	270	540
Propulsion	571	571	1142
Drop-in Tank	12	15	27
Final Assembly & Checkout	214	214	428
Sustaining Engineering	151	151	302
Sustaining Tooling	140	140	280
Initial Spares	136	136	272
Project Management	15	15	30
Fee	339	340	679
Total	3731	3735	7466
Program Office Management	37	37	74
Total Cost	3768	3772	7540
Quantity of Vehicles	23	23	64

Table A-14
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S" , 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	280	280	560
Power Supply	18	18	36
ECLS	5	5	10
Avionics	43	43	86
Propulsion	84	84	168
Drop-in Tank	2	2	4
Final Assembly & Checkout	37	37	74
Sustaining Engineering	35	35	70
Sustaining Tooling	27	27	54
Initial Spares	21	21	42
Project Management	4	4	8
Fee	56	56	112
Total	612	612	1224
Program Office Management	6	6	12
Total Cost	618	618	1236
Quantity of Vehicles	3	3	6
Intermediate Philosophy			
Thermal/Structure	1875	1875	3750
Power Supply	116	116	232
ECLS	33	33	66
Avionics	290	290	580
Propulsion	616	616	1232
Drop-in Tank	13	16	29
Final Assembly & Checkout	229	229	458
Sustaining Engineering	159	159	318
Sustaining Tooling	149	149	298
Initial Spares	147	147	294
Project Management	16	16	32
Fee	364	365	729
Total	4007	4011	8018
Program Office Management	40	40	80
Total Cost	4047	4051	8098
Quantity of Vehicles	25	25	50
Current Philosophy			
Thermal/Structure	4741	4741	9482
Power Supply	285	285	570
ECLS	84	84	168
Avionics	745	745	1490
Propulsion	1673	1673	3346
Drop-in Tank	34	41	75
Final Assembly & Checkout	552	552	1104
Sustaining Engineering	307	307	614
Sustaining Tooling	328	328	656
Initial Spares	388	388	776
Project Management	31	31	62
Fee	917	917	1834
Total	10,085	10,092	20,177
Program Office Management	101	101	202
Total Cost	10,186	10,193	20,379
Quantity of Vehicles	74	74	148

Table A-15
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	530	530	1,060
Power Supply	34	34	68
ECLS	9	9	18
Avionics	81	81	162
Propulsion	162	162	324
Drop-in Tank	4	4	8
Final Assembly & Checkout	68	68	136
Sustaining Engineering	60	60	120
Sustaining Tooling	49	49	98
Initial Spares	40	40	80
Project Management	6	6	12
Fee	104	104	208
Total	1,147	1,147	2,294
Program Office Management	11	11	22
Total Cost	1,158	1,158	2,316
Quantity of Vehicles	6	6	12
Intermediate Philosophy			
Thermal/Structure	3,282	3,282	6,564
Power Supply	199	199	398
ECLS	58	58	116
Avionics	513	513	1,026
Propulsion	1,125	1,125	2,250
Drop-in Tank	23	28	51
Final Assembly & Checkout	390	390	780
Sustaining Engineering	238	238	476
Sustaining Tooling	240	240	480
Initial Spares	264	264	528
Project Management	24	24	48
Fee	636	636	1,272
Total	6,992	6,997	13,989
Program Office Management	70	70	140
Total Cost	7,062	7,067	14,129
Quantity of Vehicles	48	48	96
Current Philosophy			
Thermal/Structure	8,018	8,018	16,036
Power Supply	475	475	950
ECLS	143	143	286
Avionics	1,272	1,272	2,544
Propulsion	2,958	2,958	5,916
Drop-in Tank	58	70	128
Final Assembly & Checkout	906	906	1,812
Sustaining Engineering	438	438	876
Sustaining Tooling	509	509	1,018
Initial Spares	674	674	1,348
Project Management	44	44	88
Fee	1,550	1,551	3,101
Total	17,045	17,058	34,103
Program Office Management	170	170	341
Total Cost	17,215	17,228	34,444
Quantity of Vehicles	138	138	276

Table A-16
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	919	835	1,754
Power Supply	58	52	110
ECLS	16	15	31
Avionics	141	128	269
Propulsion	288	262	550
Drop-in Tank	6	7	13
Final Assembly & Checkout	116	106	222
Sustaining Engineering	94	86	180
Sustaining Tooling	81	73	154
Initial Spares	70	63	133
Project Management	9	9	18
Fee	180	164	343
Total	1,978	1,800	3,778
Program Office Management	20	18	38
Total Cost	1,998	1,818	3,806
Quantity of Vehicles	11	10	21
Intermediate Philosophy			
Thermal/Structure	5,059	5,123	10,182
Power Supply	304	307	611
ECLS	90	91	181
Avionics	796	806	1,602
Propulsion	1,796	1,818	3,614
Drop-in Tank	36	44	80
Final Assembly & Checkout	587	595	1,182
Sustaining Engineering	320	324	644
Sustaining Tooling	346	350	696
Initial Spares	415	421	836
Project Management	32	32	64
Fee	978	991	1,969
Total	10,759	10,902	21,661
Program Office Management	108	109	217
Total Cost	10,867	11,011	21,878
Quantity of Vehicles			
Current Philosophy			
Thermal/Structure	12,263	12,210	24,473
Power Supply	718	714	1,432
ECLS	218	217	435
Avionics	1,959	1,951	3,910
Propulsion	4,698	4,678	9,376
Drop-in Tank	90	107	197
Final Assembly & Checkout	1,349	1,344	2,693
Sustaining Engineering	580	578	1,158
Sustaining Tooling	727	723	1,450
Initial Spares	1,055	1,051	2,106
Project Management	58	58	116
Fee	2,372	2,363	4,735
Total	26,087	25,994	52,081
Program Office Management	261	260	521
Total Cost	26,348	26,254	52,602
Quantity of Vehicles	229	228	457

Table A-17
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure			
Power Supply			
ECLS			
Avionics			
Propulsion			
Drop-in Tank			
Final Assembly & Checkout			
Sustaining Engineering			
Sustaining Tooling			
Initial Spares			
Project Management			
Fee			
Total			
Program Office Management			
Total Cost			
Quantity of Vehicles	-0-	-0-	-0-
Intermediate Philosophy			
Thermal/Structure	280	280	560
Power Supply	18	18	36
ECLS	5	5	10
Avionics	43	43	86
Propulsion	85	85	170
Drop-in Tank	1	2	3
Final Assembly & Checkout	37	37	74
Sustaining Engineering	35	35	70
Sustaining Tooling	27	27	54
Initial Spares	21	21	42
Project Management	4	4	8
Fee	56	56	112
Total	612	613	1,225
Program Office Management	6	6	12
Total Cost	618	619	1,237
Quantity of Vehicles	3	3	6
Current Philosophy			
Thermal/Structure	914	914	1,828
Power Supply	57	57	114
ECLS	16	16	32
Avionics	140	140	280
Propulsion	290	290	580
Drop-in Tank	5	8	13
Final Assembly & Checkout	116	116	232
Sustaining Engineering	92	92	184
Sustaining Tooling	79	79	158
Initial Spares	70	70	140
Project Management	9	9	18
Fee	179	179	358
Total	1,967	1,970	3,937
Program Office Management	20	20	40
Total Cost	1,987	1,990	3,977
Quantity of Vehicles	11	11	22

Table A-18
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	99	99	198
Power Supply	6	6	12
ECLS	2	2	4
Avionics	15	15	30
Propulsion	29	29	58
Drop-in Tank	1	1	2
Final Assembly & Checkout	13	13	26
Sustaining Engineering	13	13	26
Sustaining Tooling	10	10	20
Initial Spares	7	7	14
Project Management	1	1	2
Fee	20	20	40
Total	216	216	432
Program Office Management	2	2	4
Total Cost	218	218	436
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	988	988	1,976
Power Supply	62	62	124
ECLS	18	18	36
Avionics	152	152	304
Propulsion	315	315	630
Drop-in Tank	5	8	13
Final Assembly & Checkout	125	125	250
Sustaining Engineering	98	98	196
Sustaining Tooling	85	85	170
Initial Spares	76	76	152
Project Management	10	10	20
Fee	193	194	387
Total	2,127	2,131	4,258
Program Office Management	21	21	42
Total Cost	2,148	2,152	4,300
Quantity of Vehicles	12	12	24
Current Philosophy			
Thermal/Structure	2,629	2,629	5,258
Power Supply	161	161	322
ECLS	47	47	94
Avionics	409	409	818
Propulsion	895	895	1,790
Drop-in Tank	14	21	35
Final Assembly & Checkout	318	318	636
Sustaining Engineering	202	202	404
Sustaining Tooling	198	198	396
Initial Spares	210	210	420
Project Management	20	20	40
Fee	510	511	1,021
Total	5,613	5,621	11,234
Program Office Management	56	56	112
Total Cost	5,669	5,677	11,346
Quantity of Vehicles	37	37	74

Table A-19
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	281	281	562
Power Supply	18	18	36
ECLS	5	5	10
Avionics	43	43	86
Propulsion	85	85	170
Drop-in Tank	1	2	3
Final Assembly & Checkout	37	37	74
Sustaining Engineering	35	35	70
Sustaining Tooling	27	27	54
Initial Spares	21	21	42
Project Management	4	4	8
Fee	56	56	112
Total	613	614	1,227
Program Office Management	6	6	12
Total Cost	619	620	1,239
Quantity of Vehicles	3	3	6
Intermediate Philosophy			
Thermal/Structure	1,740	1,816	3,556
Power Supply	107	112	219
ECLS	31	32	63
Avionics	269	281	550
Propulsion	576	601	1,177
Drop-in Tank	9	15	24
Final Assembly & Checkout	214	224	438
Sustaining Engineering	150	156	306
Sustaining Tooling	139	145	284
Initial Spares	137	142	279
Project Management	15	16	31
Fee	339	354	693
Total	3,726	3,894	7,620
Program Office Management	37	39	76
Total Cost	3,763	3,933	7,696
Quantity of Vehicles	23	24	47
Current Philosophy			
Thermal/Structure	4,531	4,465	8,996
Power Supply	273	269	542
ECLS	80	79	159
Avionics	711	701	1,412
Propulsion	1,608	1,585	3,193
Drop-in Tank	24	38	62
Final Assembly & Checkout	532	524	1,056
Sustaining Engineering	298	294	592
Sustaining Tooling	315	311	626
Initial Spares	371	365	736
Project Management	30	29	59
Fee	877	866	1,743
Total	9,650	9,526	19,176
Program Office Management	97	95	192
Total Cost	9,747	9,621	19,368
Quantity of Vehicles	70	69	139

Table A-20
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S" , 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	450	450	900
Power Supply	28	28	56
ECLS	8	8	16
Avionics	68	68	136
Propulsion	138	138	276
Drop-in Tank	2	4	6
Final Assembly & Checkout	58	58	116
Sustaining Engineering	52	52	104
Sustaining Tooling	42	42	84
Initial Spares	34	34	68
Project Management	5	5	10
Fee	89	89	178
Total	974	976	1,950
Program Office Management	10	10	20
Total Cost	984	986	1,970
Quantity of Vehicles	5	5	10
Intermediate Philosophy			
Thermal/Structure	2,811	2,811	5,622
Power Supply	171	171	342
ECLS	50	50	100
Avionics	438	438	876
Propulsion	961	961	1,922
Drop-in Tank	15	24	39
Final Assembly & Checkout	339	339	678
Sustaining Engineering	213	213	426
Sustaining Tooling	210	210	420
Initial Spares	225	225	450
Project Management	21	21	42
Fee	545	546	1,091
Total	5,999	6,009	12,008
Program Office Management	60	60	120
Total Cost	6,059	6,069	12,128
Quantity of Vehicles	40	40	80
Current Philosophy			
Thermal/Structure	6,935	6,879	13,814
Power Supply	412	409	821
ECLS	123	122	245
Avionics	1,096	1,088	2,184
Propulsion	2,551	2,531	5,082
Drop-in Tank	38	60	98
Final Assembly & Checkout	794	788	1,582
Sustaining Engineering	398	394	792
Sustaining Tooling	451	447	898
Initial Spares	581	575	1,156
Project Management	40	39	79
Fee	1,342	1,333	2,675
Total	14,761	14,665	29,426
Program Office Management	148	147	295
Total Cost	14,909	14,812	29,721
Quantity of Vehicles	116	115	231

Table A-21
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S" , 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure			
Power Supply			
ECLS			
Avionics			
Propulsion			
Drop-in Tank			
Final Assembly & Checkout			
Sustaining Engineering			
Sustaining Tooling			
Initial Spares			
Project Management			
Fee			
Total			
Program Office Management			
Total Cost			
Quantity of Vehicles	-0-	-0-	-0-
Intermediate Philosophy			
Thermal/Structure	99	99	198
Power Supply	6	6	12
ECLS	2	2	4
Avionics	15	15	30
Propulsion	30	30	60
Drop-in Tank	--	1	1
Final Assembly & Checkout	13	13	26
Sustaining Engineering	13	13	26
Sustaining Tooling	10	10	20
Initial Spares	7	7	14
Project Management	1	1	2
Fee	20	20	40
Total	216	217	433
Program Office Management	2	2	4
Total Cost	218	219	437
Quantity of Vehicles	1	1	2
Current Philosophy			
Thermal/Structure	450	450	900
Power Supply	28	28	56
ECLS	8	8	16
Avionics	68	68	136
Propulsion	141	141	282
Drop-in Tank	--	4	4
Final Assembly & Checkout	59	59	118
Sustaining Engineering	52	52	104
Sustaining Tooling	43	43	86
Initial Spares	34	34	68
Project Management	5	5	10
Fee	89	89	178
Total	977	981	1,958
Program Office Management	10	10	20
Total Cost	987	991	1,978
Quantity of Vehicles	5	5	10

Table A-22
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50K Concept "S", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	99	99	198
Power Supply	6	6	12
ECLS	2	2	4
Avionics	15	15	30
Propulsion	30	30	60
Drop-in Tank	-	1	1
Final Assembly & Checkout	13	13	26
Sustaining Engineering	13	13	26
Sustaining Tooling	10	10	20
Initial Spares	7	7	14
Project Management	1	1	2
Fee	20	20	40
Total	216	217	433
Program Office Management	2	2	4
Total Cost	218	219	437
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	450	450	900
Power Supply	28	28	56
ECLS	8	8	16
Avionics	68	68	136
Propulsion	141	141	282
Drop-in Tank	--	4	4
Final Assembly & Checkout	59	59	118
Sustaining Engineering	52	52	104
Sustaining Tooling	43	43	86
Initial Spares	34	34	68
Project Management	5	5	10
Fee	89	89	178
Total	977	981	1,958
Program Office Management	10	10	20
Total Cost	987	991	1,978
Quantity of Vehicles	5	5	10
Current Philosophy			
Thermal/Structure	1,480	1,480	2,960
Power Supply	92	92	184
ECLS	26	26	52
Avionics	228	228	456
Propulsion	494	494	988
Drop-in Tank	--	12	12
Final Assembly & Checkout	186	186	372
Sustaining Engineering	133	133	266
Sustaining Tooling	122	122	244
Initial Spares	116	116	232
Project Management	13	13	26
Fee	289	290	579
Total	3,179	3,192	6,371
Program Office Management	32	32	64
Total Cost	3,211	3,224	6,435
Quantity of Vehicles	19	19	38

Table A-23
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	99	99	198
Power Supply	6	6	12
ECLS	2	2	4
Avionics	15	15	30
Propulsion	30	30	60
Drop-in Tank	--	1	1
Final Assembly & Checkout	13	13	26
Sustaining Engineering	13	13	26
Sustaining Tooling	10	10	20
Initial Spares	7	7	14
Project Management	1	1	2
Fee	20	20	40
Total	216	217	433
Program Office Management	2	2	4
Total Cost	218	219	437
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	916	916	1,832
Power Supply	57	57	114
ECLS	16	16	32
Avionics	140	140	280
Propulsion	297	297	594
Drop-in Tank	--	8	8
Final Assembly & Checkout	117	117	234
Sustaining Engineering	92	92	184
Sustaining Tooling	80	80	160
Initial Spares	70	70	140
Project Management	9	9	18
Fee	179	180	359
Total	1,973	1,982	3,955
Program Office Management	20	20	40
Total Cost	1,993	2,002	3,995
Quantity of Vehicles	11	11	22
Current Philosophy			
Thermal/Structure	2,510	2,510	5,020
Power Supply	153	153	306
ECLS	45	45	90
Avionics	390	390	780
Propulsion	868	868	1,736
Drop-in Tank	--	21	21
Final Assembly & Checkout	307	307	614
Sustaining Engineering	195	195	390
Sustaining Tooling	193	193	386
Initial Spares	201	201	402
Project Management	20	20	40
Fee	488	490	978
Total	5,370	5,393	10,763
Program Office Management	54	54	108
Total Cost	5,424	5,447	10,871
Quantity of Vehicles	35	35	70

Table A-24
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	192	192	384
Power Supply	12	12	24
ECLS	3	3	6
Avionics	29	29	58
Propulsion	58	58	116
Drop-in Tank	--	2	2
Final Assembly & Checkout	25	25	50
Sustaining Engineering	25	25	50
Sustaining Tooling	19	19	38
Initial Spares	14	14	28
Project Management	3	3	6
Fee	38	38	76
Total	418	420	838
Program Office Management	4	4	8
Total Cost	422	424	846
Quantity of Vehicles	2	2	4
Intermediate Philosophy			
Thermal/Structure	1,480	1,480	2,960
Power Supply	92	92	184
ECLS	26	26	52
Avionics	228	228	456
Propulsion	494	494	988
Drop-in Tank	--	12	12
Final Assembly & Checkout	186	186	372
Sustaining Engineering	133	133	266
Sustaining Tooling	122	122	244
Initial Spares	116	116	232
Project Management	13	13	26
Fee	289	290	579
Total	3,179	3,192	6,371
Program Office Management	32	32	64
Total Cost	3,211	3,224	6,435
Quantity of Vehicles	19	19	38
Current Philosophy			
Thermal/Structure	3,868	3,868	7,726
Power Supply	233	233	466
ECLS	68	68	136
Avionics	604	604	1,208
Propulsion	1,381	1,381	2,762
Drop-in Tank	--	33	33
Final Assembly & Checkout	462	462	924
Sustaining Engineering	265	265	530
Sustaining Tooling	278	278	556
Initial Spares	316	316	632
Project Management	27	27	54
Fee	750	753	1,503
Total	8,247	8,283	16,530
Program Office Management	82	83	165
Total Cost	8,329	8,366	16,695
Quantity of Vehicles	58	58	116

Table A-25
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12:5 K Concept "S", 2.5 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (203 Launches)				
Launch Operations	19.3	116.8	102.2	238.3
Propellants		(26.5)	(29.0)	(55.5)
Launch Area Support		26.4	26.9	53.3
Training & Mission Support	2.7	4.0	4.0	10.7
Age & Facility Maintenance	1.3	4.4	4.9	10.6
Recovery		19.8	19.8	39.6
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.2	15.1	15.1	30.4
Sustaining Spares	.1	25.6	27.4	53.1
Recertification		70.0	69.1	139.1
Fee	4.7	23.6	22.1	50.4
Program Office Management	3.1	18.4	17.5	39.0
Total Operations	25.8	324.6	309.2	659.6
Intermediate (205 Launches)				
Launch Operations		188.1	168.4	
Propellants		(26.8)	(29.3)	
Launch Area Support		98.4	99.9	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		9.8	10.8	
Recovery		39.7	39.7	
Transportation		29.5	29.5	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		43.2	46.2	
Recertification		1029.9	1027.1	
Fee		136.8	134.8	
Program Office Management		96.0	94.9	
Total Operations	25.8	1696.3	1676.1	3398.2
Current (208 Launches)				
Launch Operations		444.6	378.1	
Propellants		(27.1)	(29.7)	
Launch Area Support		268.1	272.2	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		22.5	24.6	
Recovery		40.3	40.3	
Transportation		31.8	31.8	
Tech Support & Sustaining Engr		25.1	25.1	
Sustaining Spares		82.0	87.9	
Recertification		1921.8	1929.4	
Fee		275.0	270.1	
Program Office Management		187.5	184.4	
Total Operations	25.8	3312.0	3257.2	6595.0

Table A-26
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept"S", 8 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (650 Launches)				
Launch Operations	46.3	340.7	320.9	707.9
Propellants		(84.8)	(92.9)	(177.7)
Launch Area Support		53.2	53.7	106.9
Training & Mission Support	2.9	4.0	4.0	10.9
Age & Facility Maintenance	1.8	6.5	7.0	15.3
Recovery		57.4	57.4	114.8
Transportation		.6	.6	1.2
Tech Support & Sustaining Engr	.2	15.1	15.1	30.4
Sustaining Spares	.2	41.9	43.7	85.8
Recertification		294.8	292.3	587.1
Fee	5.1	67.1	64.4	136.6
Program Office Management	3.4	52.9	51.5	107.8
Total Operations	59.9	934.0	910.5	1904.4
Intermediate (656 Launches)				
Launch Operations		555.9	527.9	
Propellants		(85.6)	(93.7)	
Launch Area Support		197.9	199.7	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		14.4	15.4	
Recovery		115.4	115.4	
Transportation		94.3	94.3	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		70.5	73.7	
Recertification		3213.2	3202.8	
Fee		399.1	395.1	
Program Office Management		281.1	278.9	
Total Operations	59.9	4966.7	4928.1	9954.7
Current (662 Launches)				
Launch Operations		1280.0	1176.7	
Propellants		(86.4)	(94.6)	
Launch Area Support		537.8	542.7	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		32.9	35.1	
Recovery		116.6	116.6	
Transportation		100.8	100.8	
Tech Support & Sustaining Engr		25.1	25.1	
Sustaining Spares		134.4	140.6	
Recertification		5278.0	5037.3	
Fee		721.5	711.0	
Program Office Management		494.4	488.0	
Total Operations	59.9	8734.8	8620.8	17415.5

Table A-27
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S," 15 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (1218 Launches)				
Launch Operations	74.3	616.2	595.1	1285.6
Propellants		(158.9)	(174.1)	(333.0)
Launch Area Support		79.5	80.0	159.5
Training & Mission Support	4.6	4.0	4.0	12.6
Age & Facility Maintenance	2.0	7.8	8.3	18.1
Recovery		105.1	105.1	210.2
Transportation		.9	.9	1.8
Tech Support & Sustaining Engr	.2	15.1	15.1	30.4
Sustaining Spares	.2	53.0	54.9	108.1
Recertification		617.7	613.5	1231.2
Fee	8.1	123.4	119.7	251.2
Program Office Management	5.4	97.4	95.8	198.6
Total Operations	94.8	1720.0	1692.4	3507.2
Intermediate (1231 Launches)				
Launch Operations		1012.1	980.6	
Propellants		(160.6)	(175.9)	
Launch Area Support		296.0	298.0	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		17.2	18.0	
Recovery		212.0	212.0	
Transportation		176.9	176.9	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		89.3	92.5	
Recertification		5926.3	5907.5	
Fee		720.5	714.6	
Program Office Management		508.5	505.5	
Total Operations	94.8	8983.8	8930.6	18009.2
Current (1231 Launches)				
Launch Operations		2307.8	2178.4	
Propellants		(161.6)	(176.9)	
Launch Area Support		803.0	808.3	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		39.3	41.5	
Recovery		213.3	213.3	
Transportation		188.2	188.2	
Tech Support & Sustaining Engr		25.1	25.1	
Sustaining Spares		170.5	176.8	
Recertification		9040.1	9014.5	
Fee		1223.8	1208.1	
Program Office Management		841.5	832.1	
Total Operations	94.8	14865.8	14699.7	29660.3

Table A-28
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S", 25M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (2030 Launches)				
Launch Operations	109.3	1003.2	983.7	2096.2
Propellants		(264.9)	(290.1)	(555.0)
Launch Area Support		111.0	111.6	222.6
Training & Mission Support	6.7	4.0	4.0	14.7
Age & Facility Maintenance	2.3	8.9	9.4	20.6
Recovery		173.3	173.3	346.6
Transportation		1.5	1.4	2.9
Tech Support & Sustaining Engr	.2	15.1	15.1	30.4
Sustaining Spares	.3	63.5	65.4	129.2
Recertification		1092.0	1023.0	2115.0
Fee	11.9	203.3	192.2	407.4
Program Office Management	7.8	160.5	154.7	323.0
Total Operations	138.5	2836.3	2733.8	5708.6
Intermediate (2051 Launches)				
Launch Operations		1653.2	1620.8	
Propellants		(267.6)	(293.1)	
Launch Area Support		413.6	415.7	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		19.7	20.7	
Recovery		349.8	349.8	
Transportation		294.5	294.6	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		107.1	110.3	
Recertification		9845.0	9913.3	
Fee		1179.6	1181.3	
Program Office Management		833.2	835.9	
Total Operations	138.5	14720.6	14767.2	29626.3
Current (2061 Launches)				
Launch Operations		3753.4	3600.2	
Propellants		(268.9)	(294.5)	
Launch Area Support		1121.4	1127.0	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		44.9	47.1	
Recovery		351.6	351.6	
Transportation		313.0	312.9	
Tech Support & Sustaining Engr		25.1	25.1	
Sustaining Spares		204.6	211.0	
Recertification		13978.2	13934.4	
Fee		1887.2	1866.4	
Program Office Management		1301.6	1289.3	
Total Operations	138.5	22994.3	22778.5	45911.3

Table A-29
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept"S,"2.5 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (101 Launches)				
Launch Operations	11.7	62.3	51.3	125.3
Propellants		(12.5)	(14.3)	(26.8)
Launch Area Support		18.2	18.6	36.8
Training & Mission Support	.8	4.0	4.0	8.8
Age & Facility Maintenance	1.0	3.4	3.8	8.2
Recovery		11.3	11.3	22.6
Transportation		.2	.2	.4
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.1	18.2	19.9	38.2
Recertification		51.0	50.5	101.5
Fee	1.4	16.0	14.9	32.3
Program Office Management	.9	12.0	11.4	24.3
Total Operations	16.2	211.7	200.9	428.8
Intermediate (102 Launches)				
Launch Operations		99.7	84.9	
Propellants		(12.6)	(14.4)	
Launch Area Support		67.8	69.1	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		7.5	8.2	
Recovery		22.4	22.4	
Transportation		14.8	14.8	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		30.6	33.4	
Recertification		520.1	519.2	
Fee		73.8	72.6	
Program Office Management		51.7	51.0	
Total Operations	16.2	913.2	900.6	1830.0
Current (105 Launches)				
Launch Operations		244.2	194.3	
Propellants		(13.0)	(14.8)	
Launch Area Support		185.9	189.5	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		17.2	19.2	
Recovery		23.0	23.0	
Transportation		16.1	16.1	
Tech Support & Sustaining Engr		25.1	25.1	
Sustaining Spares		58.4	63.9	
Recertification		1045.0	1055.0	
Fee		157.6	154.6	
Program Office Management		107.1	105.2	
Total Operations	16.2	1893.0	1859.2	3768.4

Table A-30
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S," 8 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (325 Launches)				
Launch Operations	28.2	177.1	161.9	367.2
Propellants		(40.3)	(45.9)	(86.2)
Launch Area Support		34.8	35.2	70.0
Training & Mission Support	1.8	4.0	4.0	9.8
Age & Facility Maintenance	1.5	5.2	5.5	12.2
Recovery		30.1	30.1	60.2
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.2	31.6	33.4	65.2
Recertification		149.1	147.7	296.8
Fee	3.2	37.7	35.7	76.6
Program Office Management	2.1	30.9	28.1	61.1
Total Operations	37.3	515.9	497.3	1050.5
Intermediate (328 Launches)				
Launch Operations		288.1	266.9	
Propellants		(40.7)	(46.3)	
Launch Area Support		129.3	131.0	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		11.6	12.6	
Recovery		60.3	60.3	
Transportation		47.2	47.2	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		53.2	56.2	
Recertification		1644.17	1639.7	
Fee		211.1	208.5	
Program Office Management		148.2	146.8	
Total Operations	37.3	2618.6	2594.2	5250.1
Current (332 Launches)				
Launch Operations		675.4	598.1	
Propellants		(41.2)	(46.9)	
Launch Area Support		352.1	356.7	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		26.5	28.7	
Recovery		61.1	61.1	
Transportation		50.6	50.6	
Tech Support & Sustaining Engr		25.1	25.2	
Sustaining Spares		101.2	107.2	
Recertification		2906.6	2910.5	
Fee		405.9	399.3	
Program Office Management		277.1	273.0	
Total Operations	37.3	4895.1	4823.8	9756.2

Table A-31
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S," 15 M LB Total Payload Delivered, 10 Years

	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (609 Launches)				
Launch Operations	45.2	316.6	300.2	662.0
Propellants		(75.5)	(86.0)	(161.5)
Launch Area Support		51.1	51.6	102.7
Training & Mission Support	2.8	4.0	4.0	10.8
Age & Facility Maintenance	1.7	6.4	6.9	15.0
Recovery		53.9	53.9	107.8
Transportation		.6	.6	1.2
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.2	40.8	42.7	83.7
Recertification		292.2	289.9	582.1
Fee	5.0	65.1	62.4	132.5
Program Office Management	3.3	50.7	49.6	103.6
Total Operations	58.5	896.6	876.8	1831.9
Intermediate (615 Launches)				
Launch Operations		519.1	494.9	
Propellants		(76.3)	(86.9)	
Launch Area Support		190.1	192.0	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		14.2	15.1	
Recovery		108.5	108.5	
Transportation		88.4	88.5	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		68.7	71.9	
Recertification		3008.2	2973.0	
Fee		374.9	368.5	
Program Office Management		263.8	260.2	
Total Operations	58.5	4660.9	4597.6	9317.0
Current (621 Launches)				
Launch Operations		1202.3	1105.2	
Propellants		(77.0)	(87.7)	
Launch Area Support		516.8	522.0	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		32.3	34.5	
Recovery		109.7	109.7	
Transportation		94.6	94.5	
Tech Support & Sustaining Engr		25.1	25.2	
Sustaining Spares		131.0	137.3	
Recertification		5002.1	5004.2	
Fee		684.6	675.4	
Program Office Management		468.7	463.3	
Total Operations	58.5	8280.6	8184.6	16523.7

Table A-32
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S," 25M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (1015 Launches)				
Launch Operations	66.5	511.9	496.1	1074.5
Propellants		(125.9)	(143.4)	(269.3)
Launch Area Support		70.6	71.2	141.8
Training & Mission Support	4.1	4.0	4.0	12.1
Age & Facility Maintenance	2.0	7.4	7.9	17.3
Recovery		88.0	88.0	176.0
Transportation		.8	.8	1.6
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.3	49.6	51.5	101.4
Recertification		551.9	548.3	1100.2
Fee	7.3	108.5	105.1	220.9
Program Office Management	4.8	84.5	83.3	172.6
Total Operations	85.3	1492.3	1471.3	3048.9
Intermediate (1025 Launches)				
Launch Operations		843.2	817.9	
Propellants		(127.1)	(144.8)	
Launch Area Support		263.0	265.1	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		16.4	17.4	
Recovery		177.4	177.4	
Transportation		147.3	147.3	
Tech Support & Sustaining Engr		18.1	18.1	
Sustaining Spares		83.5	86.7	
Recertification		5036.4	5020.5	
Fee		614.0	608.8	
Program Office Management		432.4	430.0	
Total Operations	85.3	7638.6	7596.0	15319.9
Current (1032 Launches)				
Launch Operations		1936.4	1821.2	
Propellants		(128.0)	(145.8)	
Launch Area Support		714.1	719.7	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		37.4	39.6	
Recovery		178.7	178.7	
Transportation		157.0	156.9	
Tech Support & Sustaining Engr		25.1	25.2	
Sustaining Spares		159.3	165.7	
Recertification		7746.3	7734.6	
Fee		1050.4	1037.3	
Program Office Management		721.1	713.5	
Total Operations	85.3	12739.1	12605.7	25430.1

Table A-33
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S," 2.5M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (51 Launches)				
Launch Operations	7.5	34.4	26.2	68.1
Propellants		(5.8)	(7.2)	(13.0)
Launch Area Support		13.3	13.6	26.9
Training & Mission Support	.5	4.0	4.0	8.5
Age & Facility Maintenance	.8	2.5	2.8	6.1
Recovery		7.1	7.1	14.2
Transportation		.2	.2	.4
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.1	12.3	13.7	26.1
Recertification		5.0	4.8	9.8
Fee	.9	8.1	7.3	16.3
Program Office Management	.6	6.1	5.7	12.4
Total Operations	10.7	108.0	100.6	219.3
Intermediate (51 Launches)				
Launch Operations		54.1	43.2	
Propellants		(5.8)	(7.2)	
Launch Area Support		49.2	50.4	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		5.4	6.2	
Recovery		13.8	13.8	
Transportation		7.4	7.4	
Tech Support & Sustaining Engr		18.1	18.2	
Sustaining Spares		20.6	23.1	
Recertification		269.0	269.0	
Fee		41.7	41.0	
Program Office Management		29.2	28.7	
Total Operations	10.7	515.3	507.8	1033.8
Current (53 Launches)				
Launch Operations		137.5	100.3	
Propellants		(6.0)	(7.5)	
Launch Area Support		135.2	138.4	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		12.5	14.4	
Recovery		14.3	14.3	
Transportation		8.2	8.2	
Tech Support & Sustaining Engr		25.1	25.1	
Sustaining Spares		39.3	44.2	
Recertification		556.4	566.3	
Fee		91.4	89.5	
Program Office Management		62.0	60.8	
Total Operations	10.7	1095.3	1075.0	2181.0

Table A-34
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S", 8 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (162 Launches)				
Launch Operations	17.9	92.6	81.7	192.2
Propellants		(18.3)	(22.8)	(41.1)
Launch Area Support		23.3	23.8	57.1
Training & Mission Support	1.2	4.0	4.0	9.2
Age & Facility Maintenance	1.2	4.1	4.5	9.8
Recovery		16.4	16.4	32.8
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.2	23.0	24.8	48.0
Recertification		67.1	66.4	133.5
Fee	2.1	21.1	19.8	43.0
Program Office Management	1.4	16.0	15.4	32.8
Total Operations	24.3	283.1	272.2	579.6
Intermediate (164 Launches)				
Launch Operations		150.8	135.4	
Propellants		(18.5)	(23.0)	
Launch Area Support		86.9	88.6	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		9.0	10.0	
Recovery		32.8	32.8	
Transportation		23.6	23.6	
Tech Support & Sustaining Engr		18.1	18.2	
Sustaining Spares		38.9	41.9	
Recertification		850.6	848.6	
Fee		114.3	112.6	
Program Office Management		79.9	79.1	
Total Operations	24.3	1411.8	1397.5	2833.6
Current (167 Launches)				
Launch Operations		363.4	306.4	
Propellants		(18.9)	(23.5)	
Launch Area Support		237.3	241.8	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		20.7	22.8	
Recovery		33.4	33.4	
Transportation		25.1	25.6	
Tech Support & Sustaining Engr		25.1	25.2	
Sustaining Spares		73.7	79.5	
Recertification		1587.2	1596.1	
Fee		230.2	226.2	
Program Office Management		156.6	154.2	
Total Operations	24.3	2766.8	2724.6	5515.7

Table A-35
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S", 15 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (304 Launches)				
Launch Operations	28.8	163.2	151.7	343.7
Propellants		(34.3)	(42.7)	(77.0)
Launch Area Support		33.4	33.9	67.3
Training & Mission Support	1.8	4.0	4.0	9.8
Age & Facility Maintenance	1.4	5.1	5.6	12.1
Recovery		28.3	28.3	56.6
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.3	30.7	32.5	63.5
Recertification		148.2	146.9	295.1
Fee	3.3	36.5	34.7	74.5
Program Office Management	2.2	27.9	27.2	57.3
Total Operations	38.1	492.9	480.3	1011.3
Intermediate (308 Launches)				
Launch Operations		268.4	251.2	
Propellants		(34.8)	(43.3)	
Launch Area Support		124.6	126.5	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		11.3	12.3	
Recovery		57.0	57.0	
Transportation		44.3	44.3	
Tech Support & Sustaining Engr		18.1	18.2	
Sustaining Spares		51.8	54.8	
Recertification		1553.9	1549.3	
Fee		200.0	197.6	
Program Office Management		140.2	139.1	
Total Operations	38.1	2476.3	2457.1	4971.5
Current (311 Launches)				
Launch Operations		633.1	562.0	
Propellants		(35.1)	(43.7)	
Launch Area Support		338.6	343.9	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		25.9	28.1	
Recovery		57.6	57.6	
Transportation		47.5	47.5	
Tech Support & Sustaining Engr		25.1	25.2	
Sustaining Spares		98.3	104.3	
Recertification		2757.4	2762.0	
Fee		385.7	379.5	
Program Office Management		263.0	259.4	
Total Operations	38.1	4645.5	4583.0	9266.6

Table A-36
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S," 25 M LB Total Payload Delivered, 10 Years

CONSTANT LENGTH = 165 FT.	ZERO	ORBITER	BOOSTER	TOTAL
ILRV (507 Launches)				
Launch Operations	42.4	261.3	250.8	554.5
Propellants		(57.2	(71.3)	(128.5)
Launch Area Support		45.5	46.1	91.6
Training & Mission Support	2.7	4.0	4.0	10.7
Age & Facility Maintenance	1.7	6.1	6.5	14.3
Recovery		45.4	45.4	90.8
Transportation		.5	.5	1.0
Tech Support & Sustaining Engr	.3	15.1	15.1	30.5
Sustaining Spares	.4	38.0	39.8	78.2
Recertification		251.4	249.4	500.8
Fee	4.7	56.4	54.1	115.2
Program Office Management	3.1	43.4	42.7	89.2
Total Operations	55.3	767.1	754.4	1576.8
Intermediate (513 Launches)				
Launch Operations		431.9	414.6	
Propellants		(57.9)	(72.1)	
Launch Area Support		169.8	172.0	
Training & Mission Support		6.8	6.8	
Age & Facility Maintenance		13.4	14.4	
Recovery		91.4	91.4	
Transportation		73.7	73.7	
Tech Support & Sustaining Engr		18.1	18.2	
Sustaining Spares		64.0	67.1	
Recertification		2579.5	2571.4	
Fee		322.6	319.2	
Program Office Management		226.3	224.9	
Total Operations	55.3	3997.4	3973.7	7726.4
Current (518 Launches)				
Launch Operations		1010.2	926.5	
Propellants		(58.5)	(72.8)	
Launch Area Support		461.6	467.5	
Training & Mission Support		13.3	13.3	
Age & Facility Maintenance		30.6	32.8	
Recovery		92.4	92.4	
Transportation		78.9	78.9	
Tech Support & Sustaining Engr		25.1	25.2	
Sustaining Spares		121.9	128.0	
Recertification		4303.1	4300.9	
Fee		590.7	582.2	
Program Office Management		403.7	398.9	
Total Operations	55.3	7131.5	7046.7	14233.5

Table A-37
Stage Zero Cost Summary
12.5 K Payload/Launch (Millions of 1969 Dollars)
Constant Length=165 Feet

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload = 2.5 Million Lb.				
RDT&E	156.2	14.1	155.7	54.3
Investment	1578.2	331.5	135.7	47.3
Operations	55.1	25.8	155.4	223.0
Operational Hardware (Expended)	-	-	214.3	257.9
Recurring Subtotal	1633.3	357.3	505.4	528.2
Total	1789.5	371.4	661.1	582.5
Total Payload = 8.0 Million Lb.				
RDT&E	156.2	14.1	155.7	54.3
Investment	4625.5	980.3	378.1	131.4
Operations	146.7	59.9	436.5	611.2
Operational Hardware (Expended)	-	-	583.1	702.0
Recurring Subtotal	4772.2	1040.2	1397.7	1444.6
Total	4928.4	1054.3	1553.4	1498.9
Total Payload = 15 Million Lb.				
RDT&E	156.2	14.1	155.7	54.3
Investment	8251.1	1756.7	679.9	235.2
Operations	257.7	94.8	763.4	1052.1
Operational Hardware (Expended)	-	-	994.5	1197.3
Recurring Subtotal	8503.8	1851.5	2437.8	2484.6
Total	8660.0	1865.6	2593.5	2538.9
Total Payload = 25 Million Lb.				
RDT&E	156.2	14.1	155.7	54.3
Investment	13,207.3	2821.9	1074.9	370.2
Operations	395.6	138.5	1206.8	1639.5
Operational Hardware (Expended)	-	-	1536.8	1849.9
Recurring Subtotal	13,602.9	2960.4	3818.5	3859.6
Total	13,759.1	2974.5	3974.2	3913.9

Table A-38
Stage Zero Cost Summary
25 K Payload/Launch (Millions of 1969 Dollars)

Constant Length=165 Feet

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload = 2.5 Million Lb.				
RDT&E	173.7	18.3	172.5	58.9
Investment	923.8	224.8	78.8	29.1
Operations	34.1	16.2	91.8	150.3
Operational Hardware (Expended)	-	-	130.1	150.2
Recurring Subtotal	957.9	241.0	300.7	329.6
Total	1131.6	259.3	473.2	388.5
Total Payload = 8.0 Million Lb.				
RDT&E	173.7	18.3	172.5	58.9
Investment	2731.5	700.3	233.8	86.7
Operations	90.8	37.3	256.4	412.7
Operational Hardware (Expended)	-	-	356.8	412.2
Recurring Subtotal	2822.3	737.6	847.0	911.6
Total	2996.0	755.9	1019.5	970.5
Total Payload = 15 Million Lb.				
RDT&E	173.7	18.3	172.5	58.9
Investment	4434.9	1202.7	401.7	148.8
Operations	156.2	58.5	447.9	710.5
Operational Hardware (Expended)	-	-	612.4	707.4
Recurring Subtotal	4591.1	1261.2	1462.0	1566.7
Total	4764.8	1279.5	1634.5	1625.6
Total Payload = 25 Million Lb.				
RDT&E	173.7	18.3	172.5	58.9
Investment	7813.6	1933.1	647.4	239.2
Operations	244.2	85.3	706.4	1104.0
Operational Hardware (Expended)	-	-	945.8	1092.5
Recurring Subtotal	8057.8	2018.4	2299.6	2435.7
Total	8231.5	2036.7	2472.1	2494.6

Table A-39
Stage Zero Cost Summary
50 K Payload/Launch (Millions of 1969 Dollars)

Constant Length=165 Feet

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload = 2.5 Million Lb.				
RDT&E	215.8	30.6	213.1	70.4
Investment	611.4	198.4	50.9	21.8
Operations	23.7	10.7	60.5	121.5
Operational Hardware (Expended)	-	-	88.0	94.8
Recurring Subtotal	635.1	209.1	199.4	238.1
Total	850.9	239.7	412.5	308.5
Total Payload = 8.0 Million Lb.				
RDT&E	215.8	30.6	213.1	70.4
Investment	1798.0	587.9	160.8	69.1
Operations	62.9	24.3	166.4	350.9
Operational Hardware (Expended)	-	-	240.3	259.0
Recurring Subtotal	1860.9	612.2	567.5	679.0
Total	2076.7	642.8	780.6	749.4
Total Payload = 15 Million Lb.				
RDT&E	215.8	30.6	213.1	70.4
Investment	2777.6	1058.4	264.8	114.1
Operations	108.3	38.1	291.2	606.2
Operational Hardware (Expended)	-	-	416.1	448.5
Recurring Subtotal	2885.9	1096.5	972.1	1168.8
Total	3101.7	1127.1	1185.2	1239.2
Total Payload = 25 Million Lb.				
RDT&E	215.8	30.6	213.1	70.4
Investment	5169.4	1704.1	421.7	181.8
Operations	170.1	55.3	458.9	941.7
Operational Hardware (Expended)	-	-	645.1	695.3
Recurring Subtotal	5339.5	1759.4	1525.7	1818.8
Total	5555.3	1790.0	1738.8	1889.2

Table A-40
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
Constant Length = 165 Feet

PAYLOAD SIZE = 12.5K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered = 2.5×10^6 Lb				
Launch Operations	42.4	19.3	42.9	19.4
AGE & Facility Maintenance	1.3	1.3	1.3	1.3
Recovery & Transportation			27.9	27.9
Sustaining Engineering	.7	.2	.5	.2
Sustaining Spares	.2	.1	.2	.1
Recertification			57.5	135.5
Fee & Management	7.4	3.4	16.9	26.0
Program Office Management	3.1	1.5	8.2	12.6
Total Operations	55.1	25.8	155.4	223.0
Total Payload Delivered = 8×10^6 Lb				
Launch Operations	116.1	46.3	117.4	46.5
AGE & Facility Maintenance	1.8	1.8	1.8	1.8
Recovery & Transportation			89.3	89.3
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.3	.2	.3	.2
Recertification			156.6	369.2
Fee & Management	19.7	8.0	45.9	69.4
Program Office Management	8.3	3.4	24.7	34.6
Total Operations	146.7	59.9	436.5	611.2
Total Payload Delivered = 15×10^6 Lb				
Launch Operations	201.5	74.3	203.8	74.7
AGE & Facility Maintenance	2.1	2.0	2.1	2.0
Recovery & Transportation			167.3	167.3
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.4	.2	.4	.2
Recertification			267.5	630.7
Fee & Managment	33.9	12.7	78.7	117.5
Program Office Management	14.3	5.4	43.1	59.5
Total Operations	252.7	94.8	763.4	1052.1
Total Payload Delivered = 25×10^6 Lb				
Launch Operations	317.0	109.3	320.8	109.8
AGE & Facility Maintenance	2.3	2.3	2.3	2.3
Recovery & Transportation			278.8	278.8
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.4	.3	.4	.3
Recertification			413.5	975.0
Fee & Management	53.1	18.6	122.4	180.5
Program Office Management	22.3	7.8	68.1	92.6
Total Operations	395.6	138.5	1206.8	1639.5

Table A-41
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)

Constant Length = 165 Feet

PAYLOAD SIZE = 25K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered = 2.5×10^6 Lb				
Launch Operations	25.9	11.7	26.3	11.8
AGE & Facility Maintenance	1.0	1.0	1.0	1.0
Recovery & Transportation			13.9	13.9
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.1	.1	.1	.1
Recertification			34.5	96.5
Fee & Management	4.5	2.2	10.3	18.2
Program Office Management	2.1	.9	5.2	8.5
Total Operations	34.1	16.2	91.8	150.3
Total Payload Delivered = 8×10^6 Lb				
Launch Operations	71.3	28.2	72.3	28.4
AGE & Facility Maintenance	1.5	1.5	1.5	1.5
Recovery & Transportation			44.6	44.6
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.2	.2	.2	.2
Recertification			94.8	265.3
Fee & Management	12.2	5.0	28.0	49.0
Program Office Management	5.1	2.1	14.5	23.4
Total Operations	90.8	37.3	256.4	412.7
Total Payload Delivered = 15×10^6 Lb				
Launch Operations	123.8	45.2	125.5	45.5
AGE & Facility Maintenance	1.7	1.7	1.7	1.7
Recovery & Transportation			83.6	83.6
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.3	.2	.3	.2
Recertification			162.7	455.4
Fee & Management	21.0	7.8	48.2	83.5
Program Office Management	8.9	3.3	25.4	40.3
Total Operations	156.2	58.5	447.9	710.5
Total Payload Delivered = 25×10^6 Lb				
Launch Operations	194.7	66.5	197.5	67.0
AGE & Facility Maintenance	2.0	2.0	2.0	2.0
Recovery & Transportation			139.4	139.4
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.4	.3	.4	.3
Recertification			251.6	704.1
Fee & Management	32.7	11.4	75.0	128.4
Program Office Management	13.9	4.8	40.0	62.5
Total Operations	244.2	85.3	706.4	1104.0

Table A-42
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)

Constant Length = 165 Feet

PAYLOAD SIZE = 50K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered = $2.5x10^6$ Lb				
Launch Operations	17.8	7.5	18.2	7.6
AGE & Facility Maintenance	.8	.8	.8	.8
Recovery & Transportation			7.0	7.0
Sustaining Engineering	.6	.3	.6	.3
Sustaining Spares	.1	.1	.1	.1
Recertification			23.3	89.5
Fee & Management	3.1	1.4	7.1	16.3
Program Office Management	1.3	.6	3.4	6.9
Total Operations	23.7	10.7	60.5	121.5
Total Payload Delivered = $8x10^6$ Lb				
Launch Operations	48.9	17.9	49.9	18.1
AGE & Facility Maintenance	1.2	1.2	1.2	1.2
Recovery & Transportation			22.3	22.3
Sustaining Engineering	.6	.3	.6	.3
Sustaining Spares	.2	.2	.2	.2
Recertification			63.7	244.9
Fee & Management	8.4	3.3	19.1	44.0
Program Office Management	3.6	1.4	9.4	19.9
Total Operations	62.9	24.3	166.4	350.9
Total Payload Delivered = $15x10^6$ Lb				
Launch Operations	85.4	28.8	87.2	29.1
AGE & Facility Maintenance	1.4	1.4	1.4	1.4
Recovery & Transportation			41.8	41.8
Sustaining Engineering	.6	.3	.6	.3
Sustaining Spares	.3	.3	.3	.3
Recertification			110.2	423.5
Fee & Management	14.5	5.1	33.2	75.5
Program Office Management	6.1	2.2	16.5	34.3
Total Operations	108.3	38.1	291.2	606.2
Total Payload Delivered = $25x10^6$ Lb				
Launch Operations	135.0	42.4	138.0	42.8
AGE & Facility Maintenance	1.7	1.7	1.7	1.7
Recovery & Transportation			69.6	69.6
Sustaining Engineering	.6	.3	.6	.3
Sustaining Spares	.4	.4	.4	.4
Recertification			170.9	657.1
Fee & Management	22.8	7.4	51.7	116.5
Program Office Management	9.6	3.1	26.0	53.3
Total Operations	170.1	55.3	458.9	941.7

Table A-43
Total Program Cost Summary
12.5 K Concept "S" (Millions of 1969 Dollars)

ILRV Philosophy Constant ΔV=18,790 FPS	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
Total Orbiter and Booster Cost	6,233	6,233	6,233	6,233
Total Zero Stage Cost	2,234	715	808	850
Total Program Cost	8,467	6,948	7,041	7,083
Total Payload - 8.0 Million Lb.				
Total Orbiter and Booster Cost	8,163	8,163	8,163	8,163
Total Zero Stage Cost	6,239	2,063	1,948	2,220
Total Program Cost	14,402	10,226	10,111	10,383
Total Payload - 15 Million Lb.				
Total Orbiter and Booster Cost	11,033	11,033	11,033	11,033
Total Zero Stage Cost	11,005	3,669	3,279	3,773
Total Program Cost	22,038	14,702	14,312	14,806
Total Payload - 25 Million Lb.				
Total Orbiter and Booster Cost	14,759	14,759	14,759	14,759
Total Zero Stage Cost	17,522	5,867	5,043	5,822
Total Program Cost	32,281	20,626	19,802	20,581

Table A-44
Total Program Cost Summary
25 K Concept "S" (Millions of 1969 Dollars)

ILRV Philosophy Constant ΔV=18,790 FPS	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
Total Orbiter and Booster Cost	5,798	5,798	5,798	5,798
Total Zero Stage Cost	1,296	385	518	487
Total Program Cost	7,094	6,183	6,316	6,285
Total Payload - 8.0 Million Lb.				
Total Orbiter and Booster Cost	6,809	6,809	6,809	6,809
Total Zero Stage Cost	3,509	1,106	1,160	1,252
Total Program Cost	10,318	7,915	7,969	8,061
Total Payload - 15 Million Lb.				
Total Orbiter and Booster Cost	8,339	8,339	8,339	8,339
Total Zero Stage Cost	6,134	1,943	1,881	2,108
Total Program Cost	14,473	10,282	10,220	10,447
Total Payload - 25 Million Lb.				
Total Orbiter and Booster Cost	10,460	10,460	10,460	10,460
Total Zero Stage Cost	9,723	3,135	2,864	3,241
Total Program Cost	20,183	13,595	13,324	13,701

Table A-45
Total Program Cost Summary
50 K Concept "S" (Millions of 1969 Dollars)

ILRV Philosophy Constant ΔV = 18,790 FPS	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
Total Orbiter and Booster Cost	5,909	5,909	5,909	5,909
Total Zero Stage Cost	799	226	375	305
Total Program Cost	6,708	6,135	6,284	6,214
Total Payload - 8.0 Million Lb.				
Total Orbiter and Booster Cost	6,693	6,693	6,693	6,693
Total Zero Stage Cost	2,026	630	745	739
Total Program Cost	8,719	7,323	7,438	7,432
Total Payload - 15 Million Lb.				
Total Orbiter and Booster Cost	7,113	7,113	7,113	7,113
Total Zero Stage Cost	3,535	1,114	1,151	1,229
Total Program Cost	10,648	8,227	8,264	8,342
Total Payload - 25 Million Lb.				
Total Orbiter and Booster Cost	8,225	8,225	8,225	8,225
Total Zero Stage Cost	5,504	1,777	1,704	1,877
Total Program Cost	13,729	10,002	9,929	10,102

Table A-46
Orbiter/Booster Cost Summary (Constant ΔV = 18,790)
12.5 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4320	880	5200
Investment Phase	194	194	388
Operational Phase	305	292	597
Total Program Cost	4819	1366	6185
Total Payload - 8 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4320	880	5200
Investment Phase	550	550	1100
Operational Phase	872	859	1731
Total Program Cost	5742	2289	8031
Total Payload - 15 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4320	880	5200
Investment Phase	1353	1015	2368
Operational Phase	1600	1585	3185
Total Program Cost	7273	3480	10653
Total Payload - 25 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4320	880	5200
Investment Phase	2540	1590	4130
Operational Phase	2634	2409	5043
Total Program Cost	9494	4879	14373

Table A-47
Orbiter/Booster Cost Summary (Constant ΔV = 18,790)
25 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4460	941	5401
Investment Phase	0	0	0
Operational Phase	203	194	397
Total Program Cost	4663	1135	5798
Total Payload - 8 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4460	941	5401
Investment Phase	203	203	406
Operational Phase	493	479	972
Total Program Cost	5156	1623	6779
Total Payload - 15 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4460	941	5401
Investment Phase	574	576	1150
Operational Phase	858	844	1702
Total Program Cost	5892	2361	8253
Total Payload - 25 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4460	941	5401
Investment Phase	1274	912	2186
Operational Phase	1328	1414	2742
Total Program Cost	7062	3267	10329

Table A-48
Orbiter/Booster Cost Summary (Constant ΔV = 18,790)
50 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4740	959	5699
Investment Phase	0	0	0
Operational Phase	109	101	210
Total Program Cost	4849	1060	5909
Total Payload - 8 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4740	959	5699
Investment Phase	219	221	440
Operational Phase	284	274	558
Total Program Cost	5243	1454	6697
Total Payload - 15 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4740	959	5699
Investment Phase	219	221	440
Operational Phase	495	483	978
Total Program Cost	5454	1663	7117
Total Payload - 25 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4740	959	5699
Investment Phase	628	422	1050
Operational Phase	727	759	1486
Total Program Cost	6085	2140	8225

Table A-49
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S", ILRV Philosophy, 10 Years

ΔV = 18,970 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(203 Launches)				
Total Cargo Delivered = 2.5 M LB				
Launch Operations	21.0	112.6	98.4	232.0
Propellants		(26.5)	(29.0)	(55.5)
Launch Area Support		25.3	25.8	51.1
Training & Mission Support	1.4	4.0	4.0	9.4
Age & Facility Maintenance	1.5	4.3	4.8	10.6
Recovery		19.8	19.8	39.6
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	14.2	14.3	28.8
Sustaining Spares	.3	22.6	24.6	47.5
Recertification		62.9	62.8	125.7
Fee	2.4	21.9	20.6	44.9
Program Office Management	1.5	17.3	16.5	35.3
Total Operations	28.4	305.4	291.9	625.7
(650 Launches)				
Total Cargo Delivered = 8 M LB				
Launch Operations	50.4	327.4	309.2	687.0
Propellants		(84.8)	(92.9)	(177.7)
Launch Area Support		50.4	51.2	101.6
Training & Mission Support	3.2	4.0	4.0	11.2
Age & Facility Maintenance	2.0	6.4	6.8	15.2
Recovery		57.4	57.4	114.8
Transportation		.6	.6	1.2
Tech Support & Sustaining Engr	.3	14.2	14.3	28.8
Sustaining Spares	.4	37.0	39.2	76.6
Recertification		263.3	264.2	527.5
Fee	5.6	61.8	59.6	127.0
Program Office Management	3.4	49.3	48.4	101.1
Total Operations	65.3	871.8	854.9	1,792.0
(1218 Launches)				
Total Cargo Delivered = 15 M LB				
Launch Operations	81.0	591.7	573.5	1,246.2
Propellants		(158.9)	(174.1)	(333.0)
Launch Area Support		75.2	76.2	151.4
Training & Mission Support	5.0	4.0	4.0	13.0
Age & Facility Maintenance	2.2	7.6	8.0	17.8
Recovery		105.1	105.1	210.2
Transportation		.9	.9	1.8
Tech Support & Sustaining Engr	.3	14.2	14.3	28.8
Sustaining Spares	.5	46.8	49.2	96.5
Recertification		550.8	553.8	1,104.6
Fee	8.9	113.1	100.5	232.5
Program Office Management	5.3	90.6	89.7	185.6
Total Operations	103.2	1600.0	1585.3	3,288.5

Table A-50
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S", ILRV Philosophy, 10 Years

ΔV = 18,970 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(2030 Launches)				
Total Cargo Delivered = 25 M LB				
Launch Operations	119.0	962.8	948.1	2,029.9
Propellants		(264.9)	(290.1)	(555.0)
Launch Area Support		104.9	106.2	211.1
Training & Mission Support	7.3	4.0	4.0	15.3
Age & Facility Maintenance	2.5	8.6	9.1	20.2
Recovery		173.3	173.3	346.6
Transportation		1.8	1.4	3.2
Tech Support & Sustaining Engr	.3	14.2	14.3	28.8
Sustaining Spares	.6	56.1	58.6	115.3
Recertification		973.4	793.5	1,766.9
Fee	13.0	185.9	164.4	363.3
Program Office Management	7.8	149.1	136.4	293.3
Total Operations	150.5	2,634.3	2,409.2	5,194.0

Table A-51
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S", ILRV Philosophy, 10 Years

ΔV = 18,970 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(101 Launches)				
Total Cargo Delivered = 2.5 M LB				
Launch Operations	12.4	61.0	50.2	123.6
Propellants		(12.5)	(14.3)	(26.8)
Launch Area Support		17.8	18.2	36.0
Training & Mission Support	.8	4.0	4.0	8.8
Age & Facility Maintenance	1.2	3.3	3.7	8.2
Recovery		11.3	11.3	22.6
Transportation		.2	.2	.4
Tech Support & Sustaining Engr	.3	14.5	14.6	29.4
Sustaining Spares	.2	16.9	18.6	35.7
Recertification		47.7	47.6	95.3
Fee	1.5	15.3	14.3	31.1
Program Office Management	.9	11.5	11.0	23.4
Total Operations	17.3	203.4	193.7	414.4
(325 Launches)				
Total Cargo Delivered = 8 M LB				
Launch Operations	29.9	172.8	158.3	361.0
Propellants		(40.3)	(45.9)	(86.2)
Launch Area Support		33.7	34.3	68.0
Training & Mission Support	1.9	4.0	4.0	9.9
Age & Facility Maintenance	1.7	5.2	5.6	12.5
Recovery		30.1	30.1	60.2
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	14.5	14.6	29.4
Sustaining Spares	.3	29.3	31.3	60.9
Recertification		139.1	139.1	278.2
Fee	3.4	35.8	34.1	73.3
Program Office Management	2.0	27.9	27.1	57.0
Total Operations	39.5	492.8	479.0	1011.3
(609 Launches)				
Total Cargo Delivered = 15 M LB				
Launch Operations	48.1	308.8	293.6	650.5
Propellants		(75.5)	(86.0)	(161.5)
Launch Area Support		49.4	50.2	99.6
Training & Mission Support	3.0	4.0	4.0	11.0
Age & Facility Maintenance	1.9	6.3	6.7	14.9
Recovery		53.9	53.9	107.8
Transportation		.6	.6	1.2
Tech Support & Sustaining Engr	.3	14.5	14.6	29.4
Sustaining Spares	.4	37.8	40.0	78.2
Recertification		272.5	272.8	545.3
Fee	5.4	61.8	59.6	126.8
Program Office Management	3.2	48.6	47.8	99.6
Total Operations	62.3	858.2	843.8	1764.3

Table A-52
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S "ILRV Philosophy, 10 Years

ΔV = 18,970 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(1015 Launches)				
Total Cargo Delivered = 25 M LB				
Launch Operations	70.7	498.9	485.3	1054.9
Propellants		(125.9)	(143.4)	(269.3)
Launch Area Support		68.3	69.2	137.5
Training & Mission Support	4.4	4.0	4.0	12.4
Age & Facility Maintenance	2.2	7.3	7.7	17.2
Recovery		88.0	88.0	176.0
Transportation		1.0	.8	1.8
Tech Support & Sustaining Engr	.3	14.5	14.6	29.4
Sustaining Spares	.5	45.8	48.2	94.5
Recertification		430.1	515.6	945.7
Fee	7.8	94.3	100.1	202.2
Program Office Management	4.7	75.1	80.0	159.8
Total Operations	90.6	1327.5	1413.6	2831.7

Table A-53
Operational Phase Cost Summary
(Millions of 1969 Dollars)

50 K Concept "S," ILRV Philosophy, 10 Years

ΔV = 18,970 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(51 Launches)				
Total Cargo Delivered = 2.5 M LB				
Launch Operations	7.5	34.7	26.4	68.6
Propellants		(6.0)	(7.2)	(13.2)
Launch Area Support		13.3	13.7	27.0
Training & Mission Support	.5	4.0	4.0	8.5
Age & Facility Maintenance	.9	2.5	2.8	6.2
Recovery		7.1	7.1	14.2
Transportation		.2	.2	.4
Tech Support & Sustaining Engr	.3	15.1	15.2	30.6
Sustaining Spares	.1	12.4	13.8	26.3
Recertification		5.0	4.8	9.8
Fee	.9	8.1	7.4	16.4
Program Office Management	.6	6.1	5.7	12.4
Total Operations	10.8	108.5	101.1	220.4
(162 Launches)				
Total Cargo Delivered = 8 M LB				
Launch Operations	17.9	92.9	82.0	192.8
Propellants		(18.3)	(22.8)	(41.1)
Launch Area Support		23.4	23.9	47.3
Training & Mission Support	1.2	4.0	4.0	9.2
Age & Facility Maintenance	1.4	4.0	4.5	9.9
Recovery		16.4	16.4	32.8
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	15.1	15.2	30.6
Sustaining Spares	.2	23.2	25.0	48.4
Recertification		67.6	66.9	134.5
Fee	2.1	21.2	19.9	43.2
Program Office Management	1.3	16.1	15.5	32.9
Total Operations	24.4	284.4	273.7	582.5
(304 Launches)				
Total Cargo Delivered = 15 M LB				
Launch Operations	28.8	163.6	152.3	344.7
Propellants		(34.3)	(42.7)	(77.0)
Launch Area Support		33.5	34.1	67.6
Training & Mission Support	1.8	4.0	4.0	9.8
Age & Facility Maintenance	1.6	5.2	5.6	12.4
Recovery		28.3	28.3	56.6
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.3	15.1	15.2	30.6
Sustaining Spares	.3	30.9	32.8	64.0
Recertification		149.4	148.2	297.6
Fee	3.3	36.7	34.9	74.9
Program Office Management	2.0	28.0	27.3	57.3
Total Operations	38.1	495.2	483.1	1016.4

Table A-54
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept"S", ILRV Philosophy, 10 Years

ΔV = 18,970 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(507 Launches)				
Total Cargo Delivered = 25 M LB				
Launch Operations	42.4	262.0	251.8	556.2
Propellants		(57.2)	(71.3)	(128.5)
Launch Area Support		45.7	46.4	92.1
Training & Mission Support	2.7	4.0	4.0	10.7
Age & Facility Maintenance	1.8	6.1	6.5	14.4
Recovery		45.4	45.4	90.8
Transportation		.6	.5	1.1
Tech Support & Sustaining Engr	.3	15.1	15.2	30.4
Sustaining Spares	.4	38.2	40.1	78.7
Recertification		216.0	251.7	467.7
Fee	4.8	53.0	54.4	112.2
Program Office Management	2.9	41.2	43.0	87.1
Total Operations	55.3	727.2	758.9	1541.4

Table A-55
Stage Zero Cost Summary
12.5 K Payload/Launch (Millions of 1969 Dollars)
ΔV = 18,970

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
RDT&E	147.3	13.7	184.0	58.1
Investment	2,014.4	672.5	150.3	67.0
Operations	72.0	28.4	190.1	409.0
Operational Hardware (Expended)	-	-	283.9	316.1
Subtotal (Recurring)	2,086.4	700.9	624.3	792.1
Total	2,233.7	714.6	808.3	850.2
Total Payload - 8.0 Million Lb.				
RDT&E	147.3	13.7	184.0	58.1
Investment	5,892.6	1,983.6	470.3	209.0
Operations	199.2	65.3	532.1	1,103.9
Operational Hardware (Expended)	-	-	762.1	848.7
Subtotal (Recurring)	6,091.8	2,048.9	1,764.5	2,161.6
Total	6,239.1	2,062.6	1,948.5	2,219.7
Total Payload - 15 Million Lb.				
RDT&E	147.3	13.7	184.0	58.1
Investment	10,508.5	3,551.8	866.7	383.9
Operations	349.1	103.2	932.8	1,887.4
Operational Hardware (Expended)	-	-	1,295.9	1,443.2
Subtotal (Recurring)	10,857.6	3,655.0	3,095.4	3,714.5
Total	11,004.9	3,668.7	3,279.4	3,772.6
Total Payload - 25 Million Lb.				
RDT&E	147.3	13.7	184.0	58.1
Investment	16,820.6	5,703.1	1,385.1	611.7
Operations	554.5	150.5	1,478.3	2,925.5
Operational Hardware (Expended)	-	-	1,995.5	2,226.8
Subtotal (Recurring)	17,375.1	5,853.6	4,858.9	5,764.0
Total	17,522.4	5,867.3	5,042.9	5,822.1

Table A-56
Stage Zero Cost Summary
25 K Payload/Launch (Millions of 1969 Dollars)

ΔV = 18,970

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
RDT&E	154.0	13.8	188.5	58.2
Investment	1,101.6	354.3	64.3	24.8
Operations	40.6	17.3	106.3	227.9
Operational Hardware (Expended)	-	-	158.9	176.2
Subtotal (Recurring)	1,142.2	371.6	329.5	428.9
Total	1,296.2	385.4	518.0	487.1
Total Payload - 8.0 Million Lb.				
RDT&E	154.0	13.8	188.5	58.2
Investment	3,244.3	1,052.7	252.5	110.4
Operations	110.3	39.5	294.3	612.3
Operational Hardware (Expended)	-	-	424.6	470.8
Subtotal (Recurring)	3,354.6	1,092.2	971.4	1,193.5
Total	3,508.6	1,106.0	1,159.9	1,251.7
Total Payload - 15 Million Lb.				
RDT&E	154.0	13.8	188.5	58.2
Investment	5,788.2	1,866.4	454.4	198.3
Operations	191.4	62.3	513.8	1,048.4
Operational Hardware (Expended)	-	-	724.5	803.4
Subtotal (Recurring)	5,979.6	1,928.7	1,692.7	2,050.1
Total	6,133.6	1,942.5	1,881.2	2,108.3
Total Payload - 25 Million Lb.				
RDT&E	154.0	13.8	188.5	58.2
Investment	9,266.6	3,030.1	748.9	325.9
Operations	302.0	90.6	810.8	1,620.1
Operational Hardware (Expended)	-	-	1,115.8	1,237.2
Subtotal (Recurring)	9,568.6	3,120.7	2,675.5	3,183.2
Total	9,722.6	3,134.5	2,864.0	3,241.4

Table A-57
Stage Zero Cost Summary
50 K Payload/Launch (Millions of 1969 Dollars)

$\Delta V = 18,970$

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
RDT&E	156.1	14.8	199.9	59.6
Investment	618.9	200.4	17.6	7.6
Operations	23.9	10.8	62.5	136.2
Operational Hardware (Expended)	-	-	94.5	101.8
Subtotal (Recurring)	642.8	211.2	174.6	245.6
Total	798.9	226.0	374.5	305.2
Total Payload - 8.0 Million Lb.				
RDT&E	156.1	14.8	199.9	59.6
Investment	1,807.4	590.6	131.1	57.0
Operations	62.6	24.4	168.2	357.4
Operational Hardware (Expended)	-	-	246.2	265.3
Subtotal (Recurring)	1,870.0	615.0	545.5	679.7
Total	2,026.1	629.8	745.4	739.3
Total Payload - 15 Million Lb.				
RDT&E	156.1	14.8	199.9	59.6
Investment	3,231.6	1,061.0	236.8	102.9
Operations	147.2	38.1	292.2	611.7
Operational Hardware (Expended)	-	-	421.6	454.4
Subtotal (Recurring)	3,378.8	1.099.1	950.6	1,169.0
Total	3,534.9	1,113.9	1,150.5	1,228.6
Total Payload - 25 Million Lb.				
RDT&E	156.1	14.8	199.9	59.6
Investment	5,178.5	1,706.4	395.2	171.5
Operations	169.5	55.3	459.3	945.7
Operational Hardware (Expended)	-	-	650.0	700.6
Subtotal (Recurring)	5,348.0	1,761.7	1,504.4	1,817.8
Total	5,504.1	1,776.5	1,704.3	1,877.4

Table A-58
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
ILRV Operational Philosophy

ΔV = 18,970 fps, Payload Size = 12.5K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered = 2.5×10^6				
Launch Operations	56.4	21.0	58.0	21.2
AGE & Facility Maintenance	1.5	1.5	1.5	1.5
Recovery & Transportation			27.9	27.9
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.2	.3	.3	.3
Recertification			70.3	285.3
Fee & Management	9.7	3.8	21.6	41.2
Program Office Management	3.7	1.5	10.0	21.3
Total Operations	72.0	28.4	190.1	409.0
Total Payload Delivered = 8×10^6				
Launch Operations	159.1	50.4	164.0	51.1
AGE & Facility Maintenance	2.0	2.0	2.0	2.0
Recovery & Transportation			89.3	89.3
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.4	.4	.4	.4
Recertification			188.9	767.0
Fee & Management	26.9	8.8	59.0	136.2
Program Office Management	10.3	3.4	28.0	57.6
Total Operations	199.2	65.3	532.1	1103.9
Total Payload Delivered = 15×10^6				
Launch Operations	280.7	81.0	289.7	82.0
AGE & Facility Maintenance	2.2	2.2	2.2	2.2
Recovery & Transportation			167.3	167.3
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.5	.5	.5	.5
Recertification			321.6	1305.8
Fee & Management	47.1	13.9	101.9	230.8
Program Office Management	18.1	5.3	49.1	98.5
Total Operations	349.1	103.2	932.8	1887.4
Total Payload Delivered = 25×10^6				
Launch Operations	447.5	119.0	462.0	120.5
AGE & Facility Maintenance	2.5	2.5	2.5	2.5
Recovery & Transportation			278.8	278.8
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.5	.6	.6	.6
Recertification			496.3	2015.0
Fee & Management	74.8	20.3	159.7	355.0
Program Office Management	28.7	7.8	77.9	152.8
Total Operations	554.5	150.5	1478.3	2925.5

Table A-59
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
ILRV Operational Philosophy

ΔV = 18,970 fps, Payload Size = 50K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered = 2.5×10^6				
Launch Operations	17.8	7.5	18.2	7.6
AGE & Facility Maintenance	.9	.9	.9	.9
Recovery & Transportation			7.0	7.0
Sustaining Engineering	.6	.3	.6	.3
Sustaining Spares	.1	.1	.2	.2
Recertification			24.9	95.7
Fee & Management	3.3	1.4	7.4	17.4
Program Office Management	1.2	.6	3.3	7.1
Total Operations	23.9	10.8	62.5	136.2
Total Payload Delivered = 8×10^6				
Launch Operations	48.9	17.9	49.9	18.1
AGE & Facility Maintenance	1.4	1.4	1.4	1.4
Recovery & Transportation			22.3	22.3
Sustaining Engineering	.5	.3	.6	.3
Sustaining Spares	.2	.2	.3	.3
Recertification			65.4	251.3
Fee & Management	8.4	3.3	19.5	45.1
Program Office Management	3.2	1.3	8.8	18.6
Total Operations	62.6	24.4	168.2	357.4
Total Payload Delivered = 15×10^6				
Launch Operations	83.6	28.8	87.2	29.1
AGE & Facility Maintenance	1.6	1.6	1.6	1.6
Recovery & Transportation			41.8	41.8
Sustaining Engineering	.5	.3	.6	.3
Sustaining Spares	.2	.3	.3	.3
Recertification			111.9	430.1
Fee & Management	14.2	5.1	33.5	76.6
Program Office Management	5.5	2.0	15.3	31.9
Total Operations	105.6	38.1	292.2	611.7
Total Payload Delivered = 25×10^6				
Launch Operations	135.0	42.4	138.0	42.8
AGE & Facility Maintenance	1.9	1.8	1.9	1.8
Recovery & Transportation			69.6	69.6
Sustaining Engineering	.6	.3	.6	.3
Sustaining Spares	.4	.4	.4	.4
Recertification			172.7	663.8
Fee & Management	22.8	7.5	52.0	117.7
Program Office Management	8.8	2.9	24.1	49.3
Total Operations	169.5	55.3	459.3	945.7

Table A-60
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
ILRV Operational Philosophy

ΔV = 18,970 fps, Payload Size = 25K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered = 2.5×10^6				
Launch Operations	31.1	12.4	31.9	12.6
AGE & Facility Maintenance	1.2	1.2	1.2	1.2
Recovery & Transportation			13.9	13.9
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.2	.2	.2	.2
Recertification			40.6	159.0
Fee & Management	5.5	2.3	12.4	28.8
Program Office Management	2.1	.9	5.6	11.9
Total Operations	40.6	17.3	106.3	227.9
Total Payload Delivered = 8×10^6				
Launch Operations	87.2	29.9	89.5	30.3
AGE & Facility Maintenance	1.7	1.7	1.7	1.7
Recovery & Transportation			44.6	44.6
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.3	.3	.3	.3
Recertification			108.9	426.9
Fee & Management	14.9	5.3	33.3	76.3
Program Office Management	5.7	2.0	15.5	31.9
Total Operations	110.3	39.5	294.3	612.3
Total Payload Delivered = 15×10^6				
Launch Operations	152.9	48.1	157.1	48.7
AGE & Facility Maintenance	1.9	1.9	1.9	1.9
Recovery & Transportation			83.6	83.6
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.4	.4	.4	.4
Recertification			185.9	728.4
Fee & Management	25.8	8.4	57.4	129.5
Program Office Management	9.9	3.2	27.0	54.6
Total Operations	191.4	62.3	513.8	1048.4
Total Payload Delivered = 25×10^6				
Launch Operations	242.5	70.7	249.4	71.5
AGE & Facility Maintenance	2.2	2.2	2.2	2.2
Recovery & Transportation			139.4	139.4
Sustaining Engineering	.5	.3	.5	.3
Sustaining Spares	.5	.5	.5	.5
Recertification			286.6	1123.0
Fee & Management	40.7	12.2	89.5	198.7
Program Office Management	15.6	4.7	42.7	84.5
Total Operations	302.0	90.6	810.8	1620.1

Table A-61
Total Program Cost Summary
12.5 K Concept "S" (Millions of 1969 Dollars)

ILRV Philosophy Constant ΔV=20,890 FPS	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
ILRV Philosophy				
Total Payload - 2.5 Million Lb.				
Total Orbiter and Booster Cost	6,739	6,739	6,739	6,739
Total Zero Stage Cost	1,803	373	652	582
Total Program Cost	8,542	7,112	7,391	7,321
Total Payload - 8.0 Million Lb.				
Total Orbiter and Booster Cost	8,964	8,964	8,964	8,964
Total Zero Stage Cost	5,023	1,070	1,566	1,508
Total Program Cost	13,987	10,034	10,530	10,472
Total Payload - 15 Million Lb.				
Total Orbiter and Booster Cost	12,426	12,426	12,426	12,426
Total Zero Stage Cost	8,851	1,898	2,632	2,559
Total Program Cost	21,277	14,324	15,058	14,985
Total Payload - 25 Million Lb.				
Total Orbiter and Booster Cost	16,119	16,119	16,119	16,119
Total Zero Stage Cost	14,048	3,030	4,047	3,948
Total Program Cost	30,167	19,149	20,166	20,067

Table A-62
Total Program Cost Summary
25 K Concept "S" (Millions of 1969 Dollars)

ILRV Philosophy Constant ΔV=20,890 FPS	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
Total Orbiter and Booster Cost	6,297	6,297	6,297	6,297
Total Zero Stage Cost	1,038	202	422	339
Total Program Cost	7,335	6,499	6,719	6,636
Total Payload - 8.0 Million Lb.				
Total Orbiter and Booster Cost	7,341	7,341	7,341	7,341
Total Zero Stage Cost	2,797	574	942	853
Total Program Cost	10,138	7,915	8,283	8,194
Total Payload - 15 Million Lb.				
Total Orbiter and Booster Cost	9,431	9,431	9,431	9,431
Total Zero Stage Cost	4,883	1,015	1,525	1,431
Total Program Cost	14,314	10,446	10,956	10,862
Total Payload - 25 Million Lb.				
Total Orbiter and Booster Cost	11,532	11,532	11,532	11,532
Total Zero Stage Cost	7,732	1,617	2,319	2,198
Total Program Cost	19,264	13,149	13,851	13,730

Table A-63
Total Program Cost Summary
50 K Concept "S" (Millions of 1969 Dollars)

ILRV Philosophy Constant ΔV=20,890 FPS	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
Total Orbiter and Booster Cost	6,408	6,408	6,408	6,408
Total Zero Stage Cost	652	114	307	209
Total Program Cost	7,060	6,522	6,715	6,617
Total Payload - 8.0 Million Lb.				
Total Orbiter and Booster Cost	7,219	7,219	7,219	7,219
Total Zero Stage Cost	1,633	315	607	494
Total Program Cost	8,852	7,534	7,826	7,713
Total Payload - 15 Million Lb.				
Total Orbiter and Booster Cost	7,880	7,880	7,880	7,880
Total Zero Stage Cost	2,806	555	934	816
Total Program Cost	10,686	8,435	8,814	8,696
Total Payload - 25 Million Lb.				
Total Orbiter and Booster Cost	9,162	9,162	9,162	9,162
Total Zero Stage Cost	4,407	883	1,381	1,243
Total Program Cost	13,569	10,045	10,543	10,405

Table A-64
Orbiter/Booster Cost Summary (Constant ΔV = 20,890)
12.5 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4710	958	5668
Investment Phase	218	219	437
Operational Phase	324	311	635
Total Program Cost	5252	1488	6740
Total Payload - 8 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4710	958	5668
Investment Phase	812	608	1420
Operational Phase	974	916	1890
Total Program Cost	6496	2482	8978
Total Payload - 15 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4710	958	5668
Investment Phase	1872	1498	3370
Operational Phase	1625	1825	3450
Total Program Cost	8207	4281	12488
Total Payload - 25 Million Lb.			
Contract Definition Phase	4710	958	5668
RDT & E Phase	2970	2270	5240
Investment Phase	2586	2765	5351
Operational Phase	10266	5993	16259
Total Program Cost			

Table A-65
Orbiter/Booster Cost Summary (Constant ΔV = 20,890)
25K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4890	990	5880
Investment Phase	0	0	0
Operational Phase	216	201	417
Total Program Cost	5106	1191	6297
Total Payload - 8 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4890	990	5880
Investment Phase	227	227	454
Operational Phase	526	499	1025
Total Program Cost	5643	1716	7359
Total Payload - 15 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4890	990	5880
Investment Phase	1032	830	1862
Operational Phase	853	923	1776
Total Program Cost	6775	2743	9518
Total Payload - 25 Million Lb.			
Contract Definition Phase			
RDT & E Phase	4890	990	5880
Investment Phase	1577	1387	2964
Operational Phase	1461	1371	2832
Total Program Cost	7928	3748	11676

Table A-66
Orbiter/Booster Cost Summary (Constant ΔV = 20,890)
50 K Concept "S" (Millions of 1969 Dollars)

ILRV PHILOSOPHY	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb.			
Contract Definition Phase			
RDT & E Phase	5150	1039	6189
Investment Phase	0	0	0
Operational Phase	113	106	219
Total Program Cost	5263	1145	6408
Total Payload - 8 Million Lb.			
Contract Definition Phase			
RDT & E Phase	5150	1039	6189
Investment Phase	244	245	489
Operational Phase	302	292	594
Total Program Cost	5696	1576	7272
Total Payload - 15 Million Lb.			
Contract Definition Phase			
RDT & E Phase	5150	1039	6189
Investment Phase	479	243	722
Operational Phase	534	517	1051
Total Program Cost	6163	1799	7962
Total Payload - 25 Million Lb.			
Contract Definition Phase	5150	1039	6189
RDT & E Phase	906	684	1590
Investment Phase	805	762	1567
Operational Phase	6861	2485	9346
Total Program Cost			

Table A-67
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S", ILRV Philosophy, 10 Years

ΔV = 20,890 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(203 Launches)				
Total Cargo Delivered = 2.5 M LB				
Launch Operations	19.3	116.7	102.6	238.6
Propellants		(26.5)	(29.0)	(55.5)
Launch Area Support		26.4	27.0	53.4
Training & Mission Support	1.3	4.0	4.0	9.3
Age & Facility Maintenance	1.5	4.4	4.9	10.8
Recovery		19.8	19.8	39.6
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.2	15.1	15.2	30.5
Sustaining Spares	.1	25.6	27.6	53.3
Recertification		70.0	69.7	139.7
Fee	2.2	23.6	22.2	48.0
Program Office Management	1.3	18.4	17.6	37.3
Total Operations	25.9	324.5	310.9	661.3
(650 Launches)				
Total Cargo Delivered = 8 M LB				
Launch Operations	46.4	340.4	322.1	708.9
Propellants		(84.8)	(92.9)	(177.7)
Launch Area Support		53.1	53.9	107.0
Training & Mission Support	2.9	4.0	4.0	10.9
Age & Facility Maintenance	2.0	6.5	7.0	15.5
Recovery		57.4	57.4	114.8
Transportation		.7	.6	1.3
Tech Support & Sustaining Engr	.2	15.1	15.2	30.5
Sustaining Spares	.2	41.8	44.0	74.5
Recertification		329.2	294.9	624.1
Fee	5.2	70.5	64.8	140.5
Program Office Management	3.1	55.1	51.8	110.0
Total Operations	60.0	973.9	915.7	1949.6
(1218 Launches)				
Total Cargo Delivered = 15 M LB				
Launch Operations	86.0	579.2	597.4	1251.1
Propellants		(158.9	(174.1)	(333.0)
Launch Area Support		79.4	80.4	159.8
Training & Mission Support	4.6	4.0	4.0	12.6
Age & Facility Maintenance	2.2	7.8	8.3	18.3
Recovery		105.1	105.1	210.2
Transportation		1.4	1.2	2.6
Tech Support & Sustaining Engr	.2	15.1	15.2	30.5
Sustaining Spares	.2	52.9	55.2	108.3
Recertification		573.4	724.2	1297.6
Fee	8.2	115.3	131.1	254.6
Program Office Management	4.9	92.0	103.3	200.2
Total Operations	94.8	1625.5	1825.2	3545.5

Table A-68
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "S," ILRV Philosophy, 10 Years

ΔV = 20,890 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(2030 Launches)				
Total Cargo Delivered = 25 M LB				
Launch Operations	109.5	1002.4	987.4	2099.3
Propellants		(264.9)	(290.1)	(555.0)
Launch Area Support		110.9	112.1	223.0
Training & Mission Support	6.7	4.0	4.0	14.7
Age & Facility Maintenance	2.5	8.9	9.4	20.8
Recovery		173.3	173.3	346.6
Transportation		2.2	1.7	3.9
Tech Support & Sustaining Engr	.2	15.1	15.2	30.5
Sustaining Spares	.3	63.4	65.9	129.6
Recertification		877.5	1044.5	1922.0
Fee	11.9	181.7	194.8	388.4
Program Office Management	7.2	146.4	156.5	310.1
Total Operations	138.3	2585.8	2764.7	5488.8

Table A-69
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S," ILRV Philosophy, 10 Years

ΔV = 20,890 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(101 Launches)				
Total Cargo Delivered = 2.5 M LB				
Launch Operations	11.4	63.1	49.7	124.2
Propellants		(12.5)	(14.3)	(26.8)
Launch Area Support		18.5	18.0	36.5
Training & Mission Support	.8	4.0	4.0	8.8
Age & Facility Maintenance	1.2	3.4	3.7	8.3
Recovery		11.3	11.3	22.6
Transportation		.2	.2	.4
Tech Support & Sustaining Engr	.2	15.4	14.4	30.0
Sustaining Spares	.1	18.9	20.8	39.8
Recertification		52.9	52.9	105.8
Fee	1.4	16.4	14.9	32.7
Program Office Management	.8	12.2	11.4	24.4
Total Operations	15.9	216.2	201.4	433.5
(325 Launches)				
Total Cargo Delivered = 8 M LB				
Launch Operations	27.5	179.3	156.7	363.5
Propellants		(40.3)	(45.9)	(86.2)
Launch Area Support		35.3	33.9	69.2
Training & Mission Support	1.8	4.0	4.0	9.8
Age & Facility Maintenance	1.7	5.3	5.6	12.6
Recovery		30.1	30.1	60.2
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.2	15.4	14.4	30.0
Sustaining Spares	.2	32.8	35.0	68.0
Recertification		154.6	154.7	309.3
Fee	3.1	38.6	35.8	77.5
Program Office Management	1.9	29.7	28.2	59.8
Total Operations	36.4	525.5	498.8	1060.7
(609 Launches)				
Total Cargo Delivered = 15 M LB				
Launch Operations	44.2	293.3	290.5	628.0
Propellants		(75.5)	(86.0)	(161.5)
Launch Area Support		51.9	49.5	101.4
Training & Mission Support	2.8	4.0	4.0	10.8
Age & Facility Maintenance	1.9	6.5	6.7	15.1
Recovery		53.9	53.9	107.8
Transportation		.8	.7	1.5
Tech Support & Sustaining Engr	.2	15.4	14.4	30.0
Sustaining Spares	.2	42.4	44.7	87.3
Recertification		275.6	340.2	615.8
Fee	4.9	61.4	66.4	132.7
Program Office Management	3.0	48.3	52.3	103.6
Total Operations	57.2	853.4	923.4	1834.0

Table A-70
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "S," ILRV Philosophy, 10 Years

ΔV = 20,890 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(1015 Launches)				
Total Cargo Delivered = 25 M LB				
Launch Operations	65.0	518.6	480.2	1063.8
Propellants		(125.9)	(143.4)	(269.3)
Launch Area Support		71.9	68.3	140.2
Training & Mission Support	4.0	4.0	4.0	12.0
Age & Facility Maintenance	2.2	7.5	7.7	17.4
Recovery		88.0	88.0	176.0
Transportation		1.2	1.0	2.2
Tech Support & Sustaining Engr	.2	15.4	14.4	30.0
Sustaining Spares	.2	51.4	53.9	105.5
Recertification		514.3	479.7	994.0
Fee	7.2	105.7	96.5	209.4
Program Office Management	4.3	82.7	77.6	164.6
Total Operations	83.1	1460.6	1371.4	2915.1

Table A-71
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S," ILRV Philosophy, 10 Years

ΔV = 20,890 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(51 Launches)				
Total Cargo Delivered = 2.5 M LB				
Launch Operations	6.8	35.8	27.4	70.0
Propellants		(6.0)	(7.2)	(13.2)
Launch Area Support		13.7	14.1	27.8
Training & Mission Support	.5	4.0	4.0	8.5
Age & Facility Maintenance	.9	2.5	2.9	6.3
Recovery		7.1	7.1	14.2
Transportation		.2	.2	.4
Tech Support & Sustaining Engr	.2	16.0	16.1	32.3
Sustaining Spares	.1	13.8	15.5	29.4
Recertification		5.3	5.1	10.4
Fee	.9	8.5	7.8	17.2
Program Office Management	.5	6.4	6.0	12.9
Total Operations	9.9	113.2	106.1	229.2
(162 Launches)				
Total Cargo Delivered = 8 M LB				
Launch Operations	16.3	96.1	85.3	197.7
Propellants		(18.3)	(22.8)	(41.1)
Launch Area Support		24.3	24.9	49.2
Training & Mission Support	1.1	4.0	4.0	9.1
Age & Facility Maintenance	1.4	4.2	4.7	10.3
Recovery		16.4	16.4	32.8
Transportation		.3	.3	.6
Tech Support & Sustaining Engr	.2	16.0	16.1	32.3
Sustaining Spares	.1	25.9	28.0	54.0
Recertification		74.6	74.2	148.8
Fee	1.9	22.7	21.4	46.0
Program Office Management	1.1	17.1	16.5	34.7
Total Operations	22.1	301.6	291.7	615.4
(304 Launches)				
Total Cargo Delivered = 15 M LB				
Launch Operations	26.2	149.1	158.4	333.7
Propellants		(34.3)	(42.7)	(77.0)
Launch Area Support		35.0	35.6	70.6
Training & Mission Support	1.7	4.0	4.0	9.7
Age & Facility Maintenance	1.6	5.3	5.7	12.6
Recovery		28.3	28.3	56.6
Transportation		.5	.3	.8
Tech Support & Sustaining Engr	.2	16.0	16.1	32.3
Sustaining Spares	.2	34.5	36.7	71.4
Recertification		191.0	164.6	355.6
Fee	3.0	40.1	37.8	80.9
Program Office Management	1.8	30.2	29.3	61.3
Total Operations	34.7	533.9	516.9	1085.5

Table A-72
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "S", ILRV Philosophy, 10 Years

ΔV = 20,890 FPS	ZERO	ORBITER	BOOSTER	TOTAL
(507 Launches)				
Total Cargo Delivered = 25 M LB				
Launch Operations	38.6	271.8	261.8	572.2
Propellants		(57.2)	(71.3)	(128.5)
Launch Area Support		47.8	48.6	96.4
Training & Mission Support	2.4	4.0	4.0	10.4
Age & Facility Maintenance	1.8	6.2	6.7	14.7
Recovery		45.4	45.4	90.8
Transportation		.7	.6	1.3
Tech Support & Sustaining Engr	.2	16.0	16.1	32.3
Sustaining Spares	.2	42.6	44.9	87.7
Recertification		264.8	236.6	501.4
Fee	4.3	59.6	54.7	118.6
Program Office Management	2.6	45.5	43.2	91.3
Total Operations	50.1	804.5	762.4	1617.0

Table A-73
Stage Zero Cost Summary
12.5 K Payload/Launch (Millions of 1969 Dollars)

ΔV = 20,890 FPS

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
RDT&E	121.7	6.9	148.9	46.2
Investment	1,624.7	340.1	118.2	41.4
Operations	57.0	25.9	159.5	230.1
Operational Hardware (Expended)	-	-	225.1	264.4
Subtotal (Recurring)	1,681.7	366.0	502.8	535.9
Total	1,803.4	372.9	651.7	582.1
Total Payload - 8.0 Million Lb.				
RDT&E	121.7	6.9	148.9	46.2
Investment	4,748.5	1,003.2	369.7	128.3
Operations	153.1	60.0	443.2	623.8
Operational Hardware (Expended)	-	-	604.3	709.9
Subtotal (Recurring)	4,901.6	1,063.2	1,417.2	1,462.0
Total	5,023.3	1,070.1	1,566.1	1,508.2
Total Payload - 15 Million Lb.				
RDT&E	121.7	6.9	148.9	46.2
Investment	8,464.5	1,796.4	680.8	234.6
Operations	264.4	94.8	774.7	1,071.2
Operational Hardware (Expended)	-	-	1,027.6	1,207.3
Subtotal (Recurring)	8,728.9	1,891.2	2,483.1	2,513.1
Total	8,850.6	1,898.1	2,632.0	2,559.3
Total Payload - 25 Million Lb.				
RDT&E	121.7	6.9	148.9	46.2
Investment	13,511.2	2,884.4	1,087.5	372.2
Operations	415.2	138.3	1,224.8	1,666.7
Operational Hardware (Expended)	-	-	1,585.6	1,862.7
Subtotal (Recurring)	13,926.4	3,022.7	3,897.9	3,901.6
Total	14,048.1	3,029.6	4,046.8	3,947.8

Table A-74
Stage Zero Cost Summary
25 K Payload/Launch (Millions of 1969 Dollars)

ΔV =20,890 FPS

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
RDT&E	126.6	7.0	154.0	46.2
Investment	879.0	178.6	51.0	17.5
Operations	32.5	15.9	89.9	127.9
Operational Hardware (Expended)	-	-	127.5	147.4
Subtotal (Recurring)	911.5	194.5	268.4	292.8
Total	1,038.1	201.5	422.4	339.0
Total Payload - 8.0 Million Lb.				
RDT&E	126.6	7.0	154.0	46.2
Investment	2,585.8	530.5	199.9	68.0
Operations	84.9	36.4	247.2	344.7
Operational Hardware (Expended)	-	-	340.8	393.8
Subtotal	2,670.7	566.9	787.9	806.5
Total (Recurring)	2,797.3	573.9	941.9	852.7
Total Payload - 15 Million Lb.				
RDT&E	126.6	7.0	154.0	46.2
Investment	4,611.0	950.7	359.6	121.7
Operations	145.2	57.2	429.9	591.1
Operational Hardware (Expended)	-	-	581.6	672.0
Subtotal	4,756.2	1,007.9	1,371.1	1,384.8
Total	4,882.8	1,014.9	1,525.1	1,431.0
Total Payload - 25 Million Lb.				
RDT&E	126.6	7.0	154.0	46.2
Investment	7,378.8	1,527.1	592.4	199.3
Operations	226.3	83.1	676.6	917.4
Operational Hardware (Expended)	-	-	895.6	1,034.9
Subtotal (Recurring)	7,605.1	1,610.2	2,164.6	2,151.6
Total	7,731.7	1,617.2	2,318.6	2,197.8

Table A-75
Stage Zero Cost Summary
50 K Payload/Launch (Millions of 1969 Dollars)
$\Delta V = 20{,}890$ FPS

	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload - 2.5 Million Lb.				
RDT&E	136.6	7.2	164.3	46.6
Investment	496.2	97.0	14.0	4.6
Operations	19.2	9.9	53.1	73.6
Operational Hardware (Expended)	-	-	75.1	84.2
Subtotal (Recurring)	515.4	106.9	142.2	162.4
Total	652.0	114.1	306.5	209.0
Total Payload - 8.0 Million Lb.				
RDT&E	136.6	7.2	164.3	46.6
Investment	1,447.3	285.8	104.3	34.2
Operations	48.9	22.1	142.3	193.8
Operational Hardware (Expended)	-	-	195.8	219.4
Subtotal (Recurring)	1,496.2	307.9	442.4	447.4
Total	1,632.8	315.1	606.7	494.0
Total Payload - 15 Million Lb.				
RDT&E	136.6	7.2	164.3	46.6
Investment	2,586.2	513.4	188.3	61.5
Operations	82.7	34.7	246.3	332.4
Operational Hardware (Expended)	-	-	335.3	375.8
Subtotal (Recurring)	2,668.9	548.1	769.9	769.7
Total	2,805.5	555.3	934.2	816.3
Total Payload - 25 Million Lb.				
RDT&E	136.6	7.2	164.3	46.6
Investment	4,142.1	825.7	314.0	102.2
Operations	127.8	50.1	385.9	514.9
Operational Hardware (Expended)	-	-	517.0	579.3
Subtotal (Recurring)	4,269.9	875.8	1,216.9	1,196.4
Total	4,406.5	883.0	1,381.2	1,243.0

Table A-76
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
Constant ΔV = 20,890 fps

Payload Size = 12.5K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered				
Launch Operations	44.2	19.3	44.4	19.4
AGE & Facility Maintenance	1.5	1.5	1.5	1.5
Recovery & Transportation			27.9	27.9
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.2	.1	.2	.1
Recertification			59.1	141.9
Fee & Management	7.7	3.5	17.5	27.1
Program Office Management	2.9	1.3	8.4	12.0
Total Operations	57.0	25.9	159.5	230.1
Total Payload Delivered				
Launch Operations	121.7	46.4	122.1	46.6
AGE & Facility Maintenance	2.0	2.0	2.0	2.0
Recovery & Transportation			89.3	89.3
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.3	.2	.3	.2
Recertification			158.8	381.4
Fee & Management	20.7	8.1	47.1	71.4
Program Office Management	7.9	3.1	23.4	32.7
Total Operations	153.1	60.0	443.2	623.8
Total Payload Delivered				
Launch Operations	211.9	74.5	212.5	74.9
AGE & Facility Maintenance	2.2	2.2	2.2	2.2
Recovery & Transportation			167.3	167.3
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.4	.2	.4	.2
Recertification			270.3	649.4
Fee & Management	35.7	12.8	80.6	120.7
Program Office Management	13.7	4.9	40.9	56.3
Total Operations	264.4	94.8	774.7	1071.2
Total Payload Delivered				
Launch Operations	334.2	109.5	335.1	110.1
AGE & Facility Maintenance	2.5	2.5	2.5	2.5
Recovery & Transportation			278.8	278.8
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.5	.3	.5	.3
Recertification			417.2	1002.1
Fee & Management	56.0	18.6	125.4	185.1
Program Office Management	21.5	7.2	64.8	87.6
Total Operations	415.2	138.3	1224.8	1666.7

Table A-77
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
Constant ΔV = 20,890 fps

Payload Size = 25K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered				
Launch Operations	24.5	11.4	24.7	11.5
AGE & Facility Maintenance	1.2	1.2	1.2	1.2
Recovery & Transportation			13.9	13.9
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.2	.1	.2	.1
Recertification			34.5	79.0
Fee & Management	4.4	2.2	10.2	15.3
Program Office Management	1.7	.8	4.7	6.7
Total Operations	32.5	15.9	89.9	127.9
Total Payload Delivered				
Launch Operations	66.7	27.5	67.5	27.7
AGE & Facility Maintenance	1.7	1.7	1.7	1.7
Recovery & Transportation			44.6	44.6
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.3	.2	.3	.2
Recertification			92.7	212.1
Fee & Management	11.4	4.9	26.9	40.1
Program Office Management	4.4	1.9	13.0	18.1
Total Operations	84.9	36.4	247.2	344.7
Total Payload Delivered				
Launch Operations	115.4	44.2	116.8	44.4
AGE & Facility Maintenance	1.9	1.9	1.9	1.9
Recovery & Transportation			83.6	83.6
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.3	.2	.3	.2
Recertification			158.1	362.0
Fee & Management	19.6	7.7	46.0	67.8
Program Office Management	7.5	3.0	22.7	31.0
Total Operations	145.2	57.2	429.9	251.1
Total Payload Delivered				
Launch Operations	181.0	65.0	183.2	65.3
AGE & Facility Maintenance	2.2	2.2	2.2	2.2
Recovery & Transportation			139.4	139.4
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.4	.2	.4	.2
Recertification			243.8	558.0
Fee & Management	30.5	11.2	71.4	103.9
Program Office Management	11.7	4.3	35.7	48.2
Total Operations	226.3	83.1	676.6	917.4

Table A-78
Stage Zero Operational Cost Summary
(Millions of 1969 Dollars)
Constant ΔV = 20,890 fps

Payload Size = 50K	EXPENDABLE		REUSABLE	
	LIQUID	SOLID	LIQUID	SOLID
Total Payload Delivered				
Launch Operations	14.1	6.8	14.2	6.9
AGE & Facility Maintenance	.9	.9	.9	.9
Recovery & Transportation			7.0	7.0
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.1	.1	.1	.1
Recertification			21.5	45.8
Fee & Management	2.6	1.4	6.1	8.9
Program Office Management	1.0	.5	2.8	3.8
Total Operations	19.2	9.9	53.1	73.6
Total Payload Delivered				
Launch Operations	37.7	16.3	38.0	16.4
AGE & Facility Maintenance	1.4	1.4	1.4	1.4
Recovery & Transportation			22.3	22.3
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.2	.1	.2	.1
Recertification			56.4	120.3
Fee & Management	6.6	3.0	26.0	23.0
Program Office Management	2.5	1.1	7.5	10.1
Total Operations	48.9	22.1	142.3	193.8
Total Payload Delivered				
Launch Operations	64.9	26.2	65.4	26.4
AGE & Facility Maintenance	1.6	1.6	1.6	1.6
Recovery & Transportation			41.8	41.8
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.3	.2	.3	.2
Recertification			96.5	205.9
Fee & Management	11.1	4.7	27.2	38.9
Program Office Management	4.3	1.8	13.0	17.4
Total Operations	82.7	34.7	246.3	332.4
Total Payload Delivered				
Launch Operations	101.3	38.6	102.2	38.8
AGE & Facility Maintenance	1.9	1.8	1.9	1.8
Recovery & Transportation			69.6	69.6
Sustaining Engineering	.5	.2	.5	.2
Sustaining Spares	.3	.2	.3	.2
Recertification			149.0	317.8
Fee & Management	17.2	6.7	42.1	59.5
Program Office Management	6.6	2.6	20.3	27.0
Total Operations	127.8	50.1	385.9	514.9

A2 Concept "L" Cost Estimate - Concept "L" is the designation used for the two-stage vehicle developed by McDonnell Douglas under contract NAS9-9204. The orbiter is an "HL-10" configuration modified slightly in the base area to accommodate two boost engines. The booster is a "clipped delta" configuration with ten (10) launch engines identical to those of the orbiter.

The cost estimates for the three payload sizes of this concept are presented in the following paragraphs.

A2.1 Total Program Cost - A total program cost summary is provided for each Concept "L" payload size in Tables A-79 through A-84.

A2.2 Cost Summaries by Phase - The cost estimates for the Concept "L" configuration for RDT&E, Investment, and Operational Phases are presented in Tables A-84 through A-111. Inventory requirements for the booster and orbiter are shown respectively in Figures A-5 and A-6.

INVENTORY REQUIREMENT

Concept L Booster

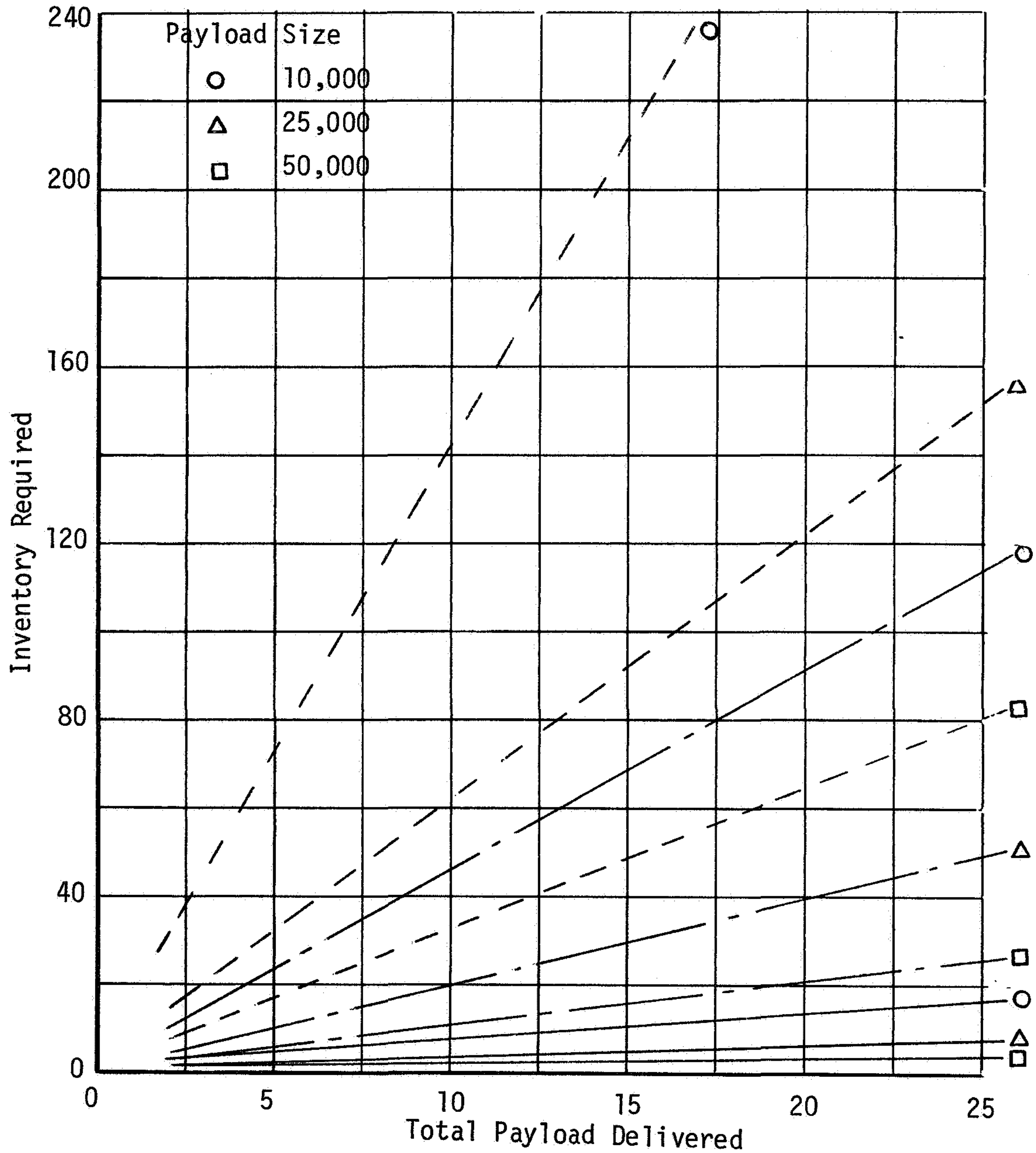


FIGURE A-5

INVENTORY REQUIREMENTS

Concept L Orbiter

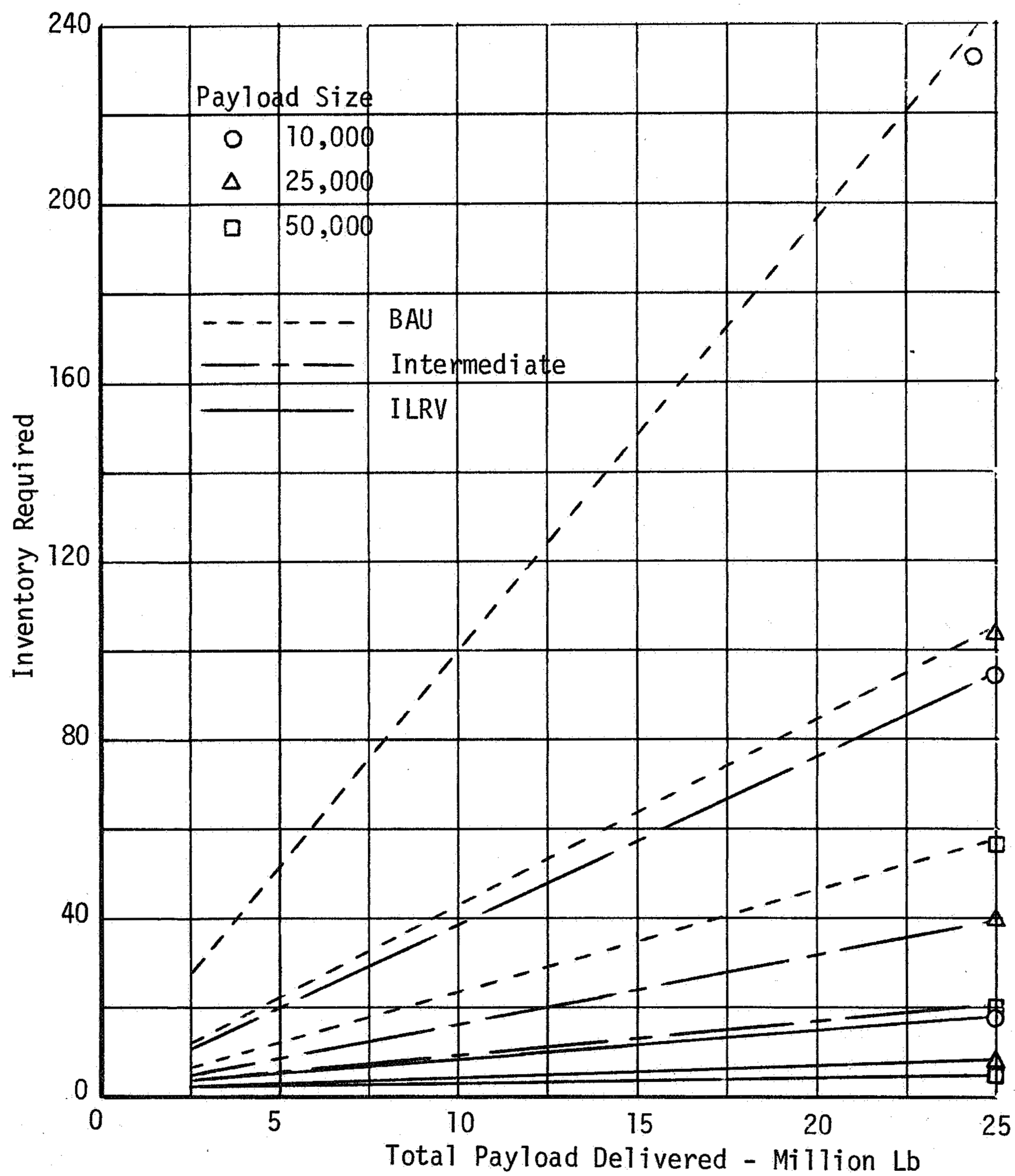


FIGURE A-6

Table A-79
Total Program Cost Summary
10 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	112	184	296
Operational Phase	309	395	704
Total Program Cost	3,481	3,513	6,994
Intermediate (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	769	1,530	2,299
Operational Phase	1,372	1,797	3,169
Total Program Cost	5,201	6,261	11,462
Current (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	2,066	4,637	6,703
Operational Phase	2,655	3,323	5,978
Total Program Cost	7,781	10,894	18,675
Total Payload - 8.0 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	415	674	1,089
Operational Phase	692	1,133	1,825
Total Program Cost	4,167	4,741	8,908
Intermediate (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	2,341	4,637	6,978
Operational Phase	3,941	5,271	9,212
Total Program Cost	9,342	12,842	22,184
Current (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	5,398	12,257	17,655
Operational Phase	6,949	8,820	15,769
Total Program Cost	15,407	24,011	39,418

Table A-80
Total Program Cost Summary
10 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 15 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	769	1,116	1,885
Operational Phase	1,384	1,825	3,209
Total Program Cost	5,213	5,875	11,088
Intermediate (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	4,025	7,966	11,991
Operational Phase	7,708	9,623	17,331
Total Program Cost	14,793	20,523	35,316
Current (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	9,129	20,644	29,773
Operational Phase	11,826	15,104	26,930
Total Program Cost	24,015	38,682	62,697
Total Payload - 25 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	1,332	2,052	3,384
Operational Phase	2,176	2,933	5,109
Total Program Cost	6,568	7,919	14,487
Intermediate (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	6,198	12,075	18,273
Operational Phase	12,359	15,742	28,101
Total Program Cost	21,617	30,751	52,368
Current (Operational Philosophy)			
Contract Definition Phase	23	14	37
RDT & E Phase	3,037	2,920	5,957
Investment Phase	13,890	31,827	45,717
Operational Phase	18,298	23,432	41,730
Total Program Cost	35,248	58,193	93,441

Table A-81
Total Program Cost Summary
25 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	0	0	0
Operational Phase	157	206	363
Total Program Cost	3,454	3,391	6,845
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	237	595	832
Operational Phase	643	880	1,523
Total Program Cost	4,177	4,660	8,837
Current (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	929	2,511	3,440
Operational Phase	1,368	1,753	3,121
Total Program Cost	5,594	7,449	13,043
Total Payload - 8.0 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	123	212	335
Operational Phase	372	520	892
Total Program Cost	3,792	3,917	7,709
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	1,105	2,365	3,470
Operational Phase	1,810	2,560	4,370
Total Program Cost	6,212	8,110	14,322
Current (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	2,773	6,818	9,591
Operational Phase	3,464	4,570	8,034
Total Program Cost	9,534	14,573	24,107

Table A-82
Total Program Cost Summary
25 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 15 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	348	595	943
Operational Phase	643	925	1,568
Total Program Cost	4,288	4,705	8,993
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	1,936	4,302	6,238
Operational Phase	3,353	4,603	7,956
Total Program Cost	8,586	12,090	20,676
Current (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	4,715	11,632	16,347
Operational Phase	5,835	7,758	13,593
Total Program Cost	13,847	22,575	36,422
Total Payload - 25 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	552	948	1,500
Operational Phase	1,058	1,550	2,608
Total Program Cost	4,907	5,683	10,590
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	3,134	6,577	9,711
Operational Phase	5,192	7,402	12,594
Total Program Cost	11,623	17,164	28,787
Current (Operational Philosophy)			
Contract Definition Phase	25	14	39
RDT & E Phase	3,272	3,171	6,443
Investment Phase	7,303	17,835	25,138
Operational Phase	8,947	11,968	20,915
Total Program Cost	19,547	32,988	52,535

Table A-83
Total Program Cost Summary
50 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	0	0	0
Operational Phase	93	112	205
Total Program Cost	3,910	3,814	7,724
Intermediate (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	149	245	394
Operational Phase	428	559	987
Total Program Cost	4,394	4,506	8,900
Current (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	543	1,496	2,039
Operational Phase	921	1,141	2,062
Total Program Cost	5,281	6,339	11,620
Total Payload - 8.0 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	150	245	395
Operational Phase	239	318	557
Total Program Cost	4,206	4,265	8,471
Intermediate (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	665	1,497	2,162
Operational Phase	1,159	1,503	2,662
Total Program Cost	5,641	6,702	12,343
Current (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	2,050	4,568	6,618
Operational Phase	2,277	2,919	5,196
Total Program Cost	8,144	11,189	19,333

Table A-84
Total Program Cost Summary
50 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 15 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	150	245	395
Operational Phase	413	567	980
Total Program Cost	4,380	4,514	8,894
Intermediate (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	1,337	2,762	4,099
Operational Phase	2,028	2,781	4,809
Total Program Cost	7,182	9,245	16,427
Current (Operational Philosophy)	28	17	45
Contract Definition Phase	3,789	3,685	7,474
RDT & E Phase	3,353	7,852	11,205
Investment Phase	3,818	4,915	8,733
Operational Phase	10,988	16,469	27,457
Total Program Cost			
Total Payload - 25 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	287	476	763
Operational Phase	641	900	1,541
Total Program Cost	4,745	5,078	9,823
Intermediate (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	2,051	4,253	6,304
Operational Phase	3,269	4,348	7,617
Total Program Cost	9,137	12,303	21,440
Current (Operational Philosophy)			
Contract Definition Phase	28	17	45
RDT & E Phase	3,789	3,685	7,474
Investment Phase	5,229	12,090	17,319
Operational Phase	5,843	7,570	13,413
Total Program Cost	14,889	23,362	38,251

Table A-85
RDT&E, Contract Definition Phase Cost Summary
10 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	15	10	25
Project Management	2	1	3
Subtotal	17	11	28
Fee	2	1	3
Subtotal	19	12	31
Program Office Management	4	2	6
Total Contract Definition	23	14	37
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	301	464	765
Power Supply	63	50	113
ECLS	34	13	47
Avionics	446	88	534
Propulsion			
Jet	65	103	168
Orbit Maneuver	0	0	0
Attitude Control	150	113	263
Main Boost	488	135	623
Total Propulsion	703	351	1054
Total Subsystems D&D	1547	966	2513
AGE & Special Test Equipment	218	231	449
Launch Facilities	30	20	50
Trainers & Simulators	95	117	212
System Integration			
System Engineering	117	163	280
Wind Tunnel Test	19	19	38
Static Fire Test	43	56	99
Ground Test Hardware	155	319	474
Flight Test Hardware	271	434	705
Flight Test Hardware Spares	21	31	52
Mockups	13	23	36
Horizontal Flight Testing	18	23	41
Vertical Flight Testing	90	79	169
Refurbishment	63	99	162
Total System Integration	810	1246	2056
Total Basic RDT&E	2700	2610	5310
Project Management	34	48	82
Subtotal	2734	2628	5362
Fee	273	263	536
Subtotal	3007	2891	5898
Program Office Management	30	29	59
Total RDT&E Phase	3037	2920	5957

Table A-86
RDT&E, Contract Definition Phase Cost Summary
25 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	17	10	27
Project Management	2	1	3
Subtotal	19	11	30
Fee	2	1	3
Subtotal	21	12	33
Program Office Management	4	2	6
Total Contract Definition	25	14	39
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	339	554	893
Power Supply	65	54	119
ECLS	34	13	47
Avionics	446	88	534
Propulsion			
Jet	78	123	201
Orbit Maneuver	0	0	0
Attitude Control	166	20	186
Main Boost	528	147	675
Total Propulsion	772	290	1062
Total Subsystems D&D	1656	999	2655
AGE & Special Test Equipment	230	272	502
Launch Facilities	30	20	50
Trainers & Simulators	102	130	232
System Integration			
System Engineering	124	176	300
Wind Tunnel Test	19	19	38
Static Fire Test	45	59	104
Ground Test Hardware	191	345	536
Flight Test Hardware	294	499	793
Flight Test Hardware Spares	23	34	57
Mockups	15	27	42
Horizontal Flight Testing	20	26	46
Vertical Flight Testing	93	84	177
Refurbishment	67	112	179
Total System Integration	891	1381	2272
Total Basic RDT&E	2909	2802	5711
Project Management	36	53	89
Subtotal	2945	2855	5800
Fee	295	285	580
Subtotal	3240	3140	6380
Program Office Management	32	31	63
Total RDT&E Phase	3272	3171	6443

Table A-87
RDT&E, Contract Definition Phase Cost Summary
50 K Concept "L" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	19	12	31
Project Management	2	1	3
Subtotal	21	13	34
Fee	2	1	3
Subtotal	23	14	37
Program Office Management	5	3	8
Total Contract Definition	28	17	45
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	437	631	1068
Power Supply	71	56	127
ECLS	34	13	47
Avionics	446	88	534
Propulsion			
Jet	104	139	243
Orbit Maneuver	0	0	0
Attitude Control	203	127	330
Main Boost	631	178	809
Total Propulsion	938	444	1382
Total Subsystems D&D	1926	1232	3158
AGE & Special Test Equipment	255	277	532
Launch Facilities	30	20	50
Trainers & Simulators	120	145	265
System Integration			
System Engineering	140	199	339
Wind Tunnel Test	19	19	38
Static Fire Test	50	70	120
Ground Test Hardware	227	402	629
Flight Test Hardware	352	577	929
Flight Test Hardware Spares	27	41	68
Mockups	18	31	49
Horizontal Flight Testing	25	29	54
Vertical Flight Testing	101	87	188
Refurbishment	79	129	208
Total System Integration	1038	1584	2622
Total Basic RDT&E	3369	3258	6627
Project Management	41	59	100
Subtotal	3410	3317	6727
Fee	341	332	673
Subtotal	3751	3649	7400
Program Office Management	38	36	74
Total RDT&E Phase	3789	3685	7474

Table A-88
Investment Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L",2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	27	54	81
Power Supply	6	5	11
ECLS	2	1	3
Avionics	17	12	29
Propulsion	18	46	64
Final Assembly & Checkout	9	12	21
Sustaining Engineering	13	19	32
Sustaining Tooling	4	7	11
Initial Spares	4	7	11
Project Management	1	2	3
Fee	10	17	27
Total	111	182	293
Program Office Management	1	2	3
Total Cost	112	184	296
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	187	454	641
Power Supply	44	40	84
ECLS	14	6	20
Avionics	117	107	224
Propulsion	137	426	563
Final Assembly & Checkout	59	95	154
Sustaining Engineering	73	122	195
Sustaining Tooling	22	54	76
Initial Spares	32	61	93
Project Management	7	12	19
Fee	69	138	207
Total	761	1515	2276
Program Office Management	8	15	23
Total Cost	769	1530	2299
Quantity of Vehicles	8	10	18
Current Philosophy			
Thermal/Structure	507	1366	1873
Power Supply	118	118	236
ECLS	38	18	56
Avionics	324	332	656
Propulsion	399	1413	1812
Final Assembly & Checkout	154	276	430
Sustaining Engineering	158	281	439
Sustaining Tooling	54	143	197
Initial Spares	92	199	291
Project Management	16	28	44
Fee	186	417	603
Total	2046	4591	6637
Program Office Management	20	46	66
Total Cost	2066	4637	6703
Quantity of Vehicles	25	36	61

Table A-89
Investment Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 8.0 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	100	200	300
Power Supply	24	18	42
ECLS	7	2	9
Avionics	62	46	108
Propulsion	71	178	249
Final Assembly & Checkout	32	42	74
Sustaining Engineering	44	62	106
Sustaining Tooling	13	26	39
Initial Spares	17	26	43
Project Management	4	6	10
Fee	37	61	98
Total	411	667	1078
Program Office Management	4	7	11
Total Cost	415	674	1089
Quantity of Vehicles	4	4	8
Intermediate Philosophy			
Thermal/Structure	576	1366	1942
Power Supply	133	118	251
ECLS	43	18	61
Avionics	369	332	701
Propulsion	457	1413	1870
Final Assembly & Checkout	174	276	450
Sustaining Engineering	173	281	454
Sustaining Tooling	60	143	203
Initial Spares	105	199	304
Project Management	17	28	45
Fee	211	417	628
Total	2318	4591	6909
Program Office Management	23	46	69
Total Cost	2341	4637	6978
Quantity of Vehicles	29	36	65
Current Philosophy			
Thermal/Structure	1334	3544	4878
Power Supply	303	299	602
ECLS	99	46	145
Avionics	870	890	1760
Propulsion	1142	4074	5216
Final Assembly & Checkout	388	690	1078
Sustaining Engineering	313	548	861
Sustaining Tooling	123	323	446
Initial Spares	256	564	820
Project Management	31	55	86
Fee	486	1103	1589
Total	5345	12,136	17,481
Program Office Management	53	121	175
Total Cost	5398	12,257	17,656
Quantity of Vehicles	78	113	191

Table A-90
Investment Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	187	331	518
Power Supply	44	29	73
ECLS	14	4	18
Avionics	117	78	195
Propulsion	137	304	441
Final Assembly & Checkout	59	70	129
Sustaining Engineering	73	95	168
Sustaining Tooling	22	41	63
Initial Spares	32	43	75
Project Management	7	10	17
Fee	69	100	169
Total	761	1105	1866
Program Office Management	8	11	19
Total Cost	769	1116	1885
Quantity of Vehicles	8	7	15
Intermediate Philosophy			
Thermal/Structure	994	2326	3320
Power Supply	227	198	425
ECLS	74	30	104
Avionics	644	576	1220
Propulsion	827	2548	3375
Final Assembly & Checkout	293	461	754
Sustaining Engineering	255	410	665
Sustaining Tooling	96	225	321
Initial Spares	187	355	542
Project Management	26	41	67
Fee	362	717	1079
Total	3985	7887	11,872
Program Office Management	40	79	119
Total Cost	4025	7966	11,991
Quantity of Vehicles	55	68	123
Current Philosophy			
Thermal/Structure	2256	5879	8135
Power Supply	506	490	996
ECLS	169	78	247
Avionics	1488	1504	2992
Propulsion	2032	7181	9213
Final Assembly & Checkout	637	1120	1757
Sustaining Engineering	446	772	1218
Sustaining Tooling	191	496	687
Initial Spares	447	985	1432
Project Management	45	77	122
Fee	822	1858	2680
Total	9039	20,440	29,479
Program Office Management	90	204	294
Total Cost	9129	20,644	29,773
Quantity of Vehicles	146	209	355

Table A-91
Investment Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	326	609	935
Power Supply	76	53	129
ECLS	24	8	32
Avionics	206	145	351
Propulsion	247	584	831
Final Assembly & Checkout	101	126	227
Sustaining Engineering	113	154	267
Sustaining Tooling	37	70	107
Initial Spares	58	83	141
Project Management	11	15	26
Fee	120	185	305
Total	1319	2032	3351
Program Office Management	13	20	33
Total Cost	1332	2052	3384
Quantity of Vehicles	15	14	29
Intermediate Philosophy			
Thermal/Structure	1533	3492	5025
Power Supply	347	295	642
ECLS	114	46	160
Avionics	1002	877	1879
Propulsion	1329	4007	5336
Final Assembly & Checkout	442	680	1122
Sustaining Engineering	344	543	887
Sustaining Tooling	138	319	457
Initial Spares	296	555	851
Project Management	34	54	88
Fee	558	1087	1645
Total	6137	11,955	18,092
Program Office Management	61	120	181
Total Cost	6198	12,075	18,273
Quantity of Vehicles	92	111	203
Current Philosophy			
Thermal/Structure	3426	8929	12,355
Power Supply	761	736	1497
ECLS	256	119	375
Avionics	2281	2370	4601
Propulsion	3220	11,484	14,704
Final Assembly & Checkout	944	1669	2613
Sustaining Engineering	587	1018	1605
Sustaining Tooling	271	706	977
Initial Spares	697	1564	2261
Project Management	59	102	161
Fee	1250	2865	4115
Total	13,752	31,512	45,264
Program Office Management	138	315	453
Total Cost	13,890	31,827	45,717
Quantity of Vehicles	241	348	589

Table A-92
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L",2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure			
Power Supply			
ECLS			
Avionics			
Propulsion			
Final Assembly & Checkout			
Sustaining Engineering			
Sustaining Tooling			
Initial Spares			
Project Management			
Fee			
Total			
Program Office Management			
Total Cost			
Quantity of Vehicles	-0-	-0-	-0-
Intermediate Philosophy			
Thermal/Structure	60	189	249
Power Supply	13	14	27
ECLS	4	2	6
Avionics	32	35	67
Propulsion	41	153	194
Final Assembly & Checkout	18	37	55
Sustaining Engineering	26	54	80
Sustaining Tooling	8	24	32
Initial Spares	9	22	31
Project Management	3	5	8
Fee	21	54	75
Total	235	589	824
Program Office Management	2	6	8
Total Cost	237	595	832
Quantity of Vehicles	2	3	5
Current Philosophy			
Thermal/Structure	239	796	1035
Power Supply	50	59	109
ECLS	15	8	23
Avionics	131	154	285
Propulsion	173	710	883
Final Assembly & Checkout	69	150	219
Sustaining Engineering	84	176	260
Sustaining Tooling	28	89	117
Initial Spares	39	100	139
Project Management	8	18	26
Fee	84	226	310
Total	920	2486	3406
Program Office Management	9	25	34
Total Cost	929	2511	3440
Quantity of Vehicles	9	15	24

Table A-93
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L",8.0 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	31	67	98
Power Supply	7	5	12
ECLS	2	1	3
Avionics	17	12	29
Propulsion	21	53	74
Final Assembly & Checkout	9	13	22
Sustaining Engineering	14	21	35
Sustaining Tooling	4	9	13
Initial Spares	5	8	13
Project Management	1	2	3
Fee	11	19	30
Total	122	210	332
Program Office Management	1	2	3
Total Cost	123	212	335
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	285	749	1034
Power Supply	59	56	115
ECLS	18	8	26
Avionics	156	145	301
Propulsion	208	665	873
Final Assembly & Checkout	82	142	224
Sustaining Engineering	97	168	265
Sustaining Tooling	32	85	117
Initial Spares	47	94	141
Project Management	10	17	27
Fee	100	213	313
Total	1094	2342	3436
Program Office Management	11	23	34
Total Cost	1105	2365	3470
Quantity of Vehicles	11	14	25
Current Philosophy			
Thermal/Structure	721	2139	2860
Power Supply	148	155	303
ECLS	47	22	69
Avionics	402	426	828
Propulsion	566	2099	2665
Final Assembly & Checkout	201	391	592
Sustaining Engineering	195	365	560
Sustaining Tooling	72	211	283
Initial Spares	124	292	416
Project Management	20	36	56
Fee	250	614	864
Total	2746	6750	9496
Program Office Management	27	68	95
Total Cost	2773	6818	9591
Quantity of Vehicles	32	48	80

Table A-94
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	89	189	278
Power Supply	19	14	33
ECLS	6	2	8
Avionics	47	35	82
Propulsion	61	153	214
Final Assembly & Checkout	26	37	63
Sustaining Engineering	37	54	91
Sustaining Tooling	11	24	35
Initial Spares	14	22	36
Project Management	4	5	9
Fee	31	54	85
Total	345	589	934
Program Office Management	3	6	9
Total Cost	348	595	943
Quantity of Vehicles	3	3	6
Intermediate Philosophy			
Thermal/Structure	502	1358	1860
Power Supply	104	100	204
ECLS	32	14	46
Avionics	278	267	545
Propulsion	382	1272	1654
Final Assembly & Checkout	142	252	394
Sustaining Engineering	150	262	412
Sustaining Tooling	53	143	196
Initial Spares	85	178	263
Project Management	15	26	41
Fee	174	387	561
Total	1917	4259	6176
Program Office Management	19	43	62
Total Cost	1936	4302	6238
Quantity of Vehicles	21	28	49
Current Philosophy			
Thermal/Structure	1231	3611	4842
Power Supply	249	259	508
ECLS	80	38	118
Avionics	694	733	1427
Propulsion	1011	3755	4766
Final Assembly & Checkout	334	647	981
Sustaining Engineering	284	526	810
Sustaining Tooling	114	330	444
Initial Spares	219	518	737
Project Management	28	53	81
Fee	424	1047	1471
Total	4668	11,517	16,185
Program Office Management	47	115	162
Total Cost	4715	11,632	16,347
Quantity of Vehicles	60	90	150

Table A-95
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	141	301	442
Power Supply	30	23	53
ECLS	9	3	12
Avionics	76	57	133
Propulsion	99	251	350
Final Assembly & Checkout	41	58	99
Sustaining Engineering	55	80	135
Sustaining Tooling	17	37	54
Initial Spares	23	36	59
Project Management	6	8	14
Fee	50	85	135
Total	547	939	1486
Program Office Management	5	9	14
Total Cost	552	948	1500
Quantity of Vehicles	5	5	10
Intermediate Philosophy			
Thermal/Structure	816	2064	2880
Power Supply	167	150	317
ECLS	53	22	75
Avionics	456	411	867
Propulsion	647	2018	2665
Final Assembly & Checkout	226	378	604
Sustaining Engineering	213	355	568
Sustaining Tooling	80	205	285
Initial Spares	142	281	423
Project Management	21	36	57
Fee	282	592	874
Total	3103	6512	9615
Program Office Management	31	65	96
Total Cost	3134	6577	9711
Quantity of Vehicles	37	46	83
Current Philosophy			
Thermal/Structure	1908	5476	7384
Power Supply	382	389	771
ECLS	124	59	183
Avionics	1086	1128	2214
Propulsion	1634	5978	7612
Final Assembly & Checkout	505	964	1469
Sustaining Engineering	384	699	1083
Sustaining Tooling	165	471	636
Initial Spares	348	819	1167
Project Management	38	70	108
Fee	657	1605	2262
Total	1231	17,658	24,889
Program Office Management	72	177	249
Total Cost	7303	17,835	25,138
Quantity of Vehicles	101	149	250

Table A-96
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure			
Power Supply			
ECLS			
Avionics			
Propulsion			
Final Assembly & Checkout			
Sustaining Engineering			
Sustaining Tooling			
Initial Spares			
Project Management			
Fee			
Total			
Program Office Management			
Total Cost			
Quantity of Vehicles	-0-	-0-	-0-
Intermediate Philosophy			
Thermal/Structure	42	77	119
Power Supply	7	5	12
ECLS	2	1	3
Avionics	17	12	29
Propulsion	27	66	93
Final Assembly & Checkout	11	15	26
Sustaining Engineering	16	24	40
Sustaining Tooling	5	10	15
Initial Spares	6	9	15
Project Management	2	2	4
Fee	13	22	35
Total	148	243	391
Program Office Management	1	2	3
Total Cost	149	245	394
Quantity of Vehicles	1	1	2
Current Philosophy			
Thermal/Structure	155	468	623
Power Supply	25	31	56
ECLS	7	4	11
Avionics	62	78	140
Propulsion	103	433	536
Final Assembly & Checkout	39	89	128
Sustaining Engineering	53	118	171
Sustaining Tooling	18	56	74
Initial Spares	22	58	80
Project Management	5	12	17
Fee	49	134	183
Total	538	1481	2019
Program Office Management	5	15	20
Total Cost	543	1496	2039
Quantity of Vehicles	4	7	11

Table A-97
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 8.0 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	42	77	119
Power Supply	7	5	12
ECLS	2	1	3
Avionics	17	12	29
Propulsion	27	66	93
Final Assembly & Checkout	11	15	26
Sustaining Engineering	16	24	40
Sustaining Tooling	5	10	15
Initial Spares	6	9	15
Project Management	2	2	4
Fee	14	22	36
Total	149	243	392
Program Office Management	1	2	3
Total Cost	150	245	395
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	190	468	658
Power Supply	31	31	62
ECLS	9	4	13
Avionics	76	78	154
Propulsion	127	433	560
Final Assembly & Checkout	48	89	137
Sustaining Engineering	62	118	180
Sustaining Tooling	22	56	78
Initial Spares	27	58	85
Project Management	6	12	18
Fee	60	135	195
Total	658	1482	2140
Program Office Management	7	15	22
Total Cost	665	1497	2162
Quantity of Vehicles	5	7	12
Current Philosophy			
Thermal/Structure	594	1418	2012
Power Supply	95	94	189
ECLS	28	13	41
Avionics	243	242	485
Propulsion	425	1434	1859
Final Assembly & Checkout	143	262	405
Sustaining Engineering	154	279	433
Sustaining Tooling	60	151	211
Initial Spares	88	191	279
Project Management	15	28	43
Fee	185	411	596
Total	2030	4523	6553
Program Office Management	20	45	65
Total Cost	2050	4568	6618
Quantity of Vehicles	18	25	43

Table A-98
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	42	77	119
Power Supply	7	5	12
ECLS	2	1	3
Avionics	17	12	29
Propulsion	27	66	93
Final Assembly & Checkout	11	15	26
Sustaining Engineering	16	24	40
Sustaining Tooling	5	10	15
Initial Spares	6	9	15
Project Management	2	2	4
Fee	14	22	36
Total	149	243	392
Program Office Management	1	2	3
Total Cost	150	245	395
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	386	862	1248
Power Supply	62	57	119
ECLS	18	8	26
Avionics	156	145	301
Propulsion	268	833	1101
Final Assembly & Checkout	95	162	257
Sustaining Engineering	111	191	302
Sustaining Tooling	41	97	138
Initial Spares	56	112	168
Project Management	11	19	30
Fee	120	249	369
Total	1324	2735	4059
Program Office Management	13	27	40
Total Cost	1337	2762	4099
Quantity of Vehicles			
Current Philosophy			
Thermal/Structure	975	2417	3392
Power Supply	155	158	313
ECLS	47	22	69
Avionics	402	419	821
Propulsion	725	2579	3304
Final Assembly & Checkout	230	439	669
Sustaining Engineering	222	411	633
Sustaining Tooling	92	239	331
Initial Spares	148	342	490
Project Management	22	41	63
Fee	302	707	1009
Total	3320	7774	11,094
Program Office Management	33	78	111
Total Cost	3353	7852	11,205
Quantity of Vehicles			

Table A-99
Investment Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	81	149	230
Power Supply	13	10	23
ECLS	4	1	5
Avionics	32	24	56
Propulsion	53	130	183
Final Assembly & Checkout	21	29	50
Sustaining Engineering	30	44	74
Sustaining Tooling	10	19	29
Initial Spares	11	18	29
Project Management	3	4	7
Fee	26	43	69
Total	284	471	755
Program Office Management	3	5	8
Total Cost	287	476	763
Quantity of Vehicles	2	2	4
Intermediate Philosophy			
Thermal/Structure	594	1321	1915
Power Supply	95	87	182
ECLS	28	12	40
Avionics	243	225	468
Propulsion	425	1327	1752
Final Assembly & Checkout	143	245	388
Sustaining Engineering	154	265	419
Sustaining Tooling	61	142	203
Initial Spares	88	177	265
Project Management	15	27	42
Fee	185	383	568
Total	2031	4211	6242
Program Office Management	20	42	62
Total Cost	2051	4253	6304
Quantity of Vehicles	18	23	41
Current Philosophy			
Thermal/Structure	1523	3687	5210
Power Supply	240	238	478
ECLS	73	34	107
Avionics	634	648	1282
Propulsion	1176	4122	5298
Final Assembly & Checkout	352	659	1011
Sustaining Engineering	305	553	858
Sustaining Tooling	135	343	478
Initial Spares	237	543	780
Project Management	31	55	86
Fee	471	1088	1559
Total	5177	11,970	17,147
Program Office Management	52	120	172
Total Cost	5229	12,090	17,319
Quantity of Vehicles	54	78	132

Table A-100
Operational Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 2.5 MLB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (254 Launches)			
Launch Operations	95.5	123.4	218.9
Propellants	(13.9)	(44.8)	(58.7)
Launch Area Support	22.7	27.2	49.9
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	4.1	4.9	9.0
Recovery	24.1	24.1	48.2
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	10.4	13.0	23.4
Sustaining Spares	16.3	24.6	40.9
Recertification	91.1	123.3	214.4
Fee	23.0	27.6	50.6
Program Office Management	17.5	22.3	39.8
Total Operations	309.1	394.7	703.8
Intermediate (256 Launches)			
Launch Operations	157.6	194.4	352.0
Propellants	(14.0)	(45.2)	(59.2)
Launch Area Support	84.3	101.0	185.3
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	9.1	10.8	19.9
Recovery	48.2	48.2	96.4
Transportation	36.7	37.0	73.7
Tech Support & Sustaining Engr	12.5	15.6	28.1
Sustaining Spares	27.4	41.3	68.7
Recertification	803.0	1097.6	1900.6
Fee	108.7	142.2	250.9
Program Office Management	77.6	101.7	179.3
Total Operations	1372.0	1796.6	3168.6
Current (260 Launches)			
Launch Operations	388.8	420.0	808.8
Propellants	(14.2)	(45.9)	60.1
Launch Area Support	229.8	275.3	505.1
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	20.7	24.7	45.4
Recovery	49.0	49.0	98.0
Transportation	39.2	40.5	79.7
Tech Support & Sustaining Engr	17.3	21.7	39.0
Sustaining Spares	52.5	77.8	130.3
Recertification	1476.0	1939.7	3415.7
Fee	218.4	272.7	491.1
Program Office Management	150.3	188.1	338.4
Total Operations	2655.5	3322.9	5978.4

Table A-101
Operational Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (812 Launches)			
Launch Operations	239.7	387.7	627.4
Propellants	(39.0)	(143.3)	(182.3)
Launch Area Support	40.8	54.1	94.9
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	5.7	6.9	12.6
Recovery	62.6	71.0	133.6
Transportation	.7	.7	1.4
Tech Support & Sustaining Engr	10.4	13.0	23.4
Sustaining Spares	24.9	38.7	63.6
Recertification	213.7	415.5	629.2
Fee	50.0	77.7	127.7
Program Office Management	39.1	64.2	103.3
Total Operations	691.5	1133.4	1824.9
Intermediate (820 Launches)			
Launch Operations	456.9	610.7	1067.6
Propellants	(44.9)	(144.7)	(189.6)
Launch Area Support	164.4	201.4	365.8
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	13.0	15.3	28.3
Recovery	143.0	143.0	286.0
Transportation	117.5	118.4	235.9
Tech Support & Sustaining Engr	12.5	15.6	28.1
Sustaining Spares	44.1	65.0	109.1
Recertification	2449.6	3381.0	5830.6
Fee	310.2	415.1	725.3
Program Office Management	223.1	298.3	521.4
Total Operations	3941.1	5270.6	9211.7
Current (826 Launches)			
Launch Operations	1094.8	1305.6	2400.4
Propellants	(45.2)	(145.8)	(191.0)
Launch Area Support	446.3	546.9	993.2
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	29.6	34.7	64.3
Recovery	144.1	144.1	288.2
Transportation	124.0	128.0	252.0
Tech Support & Sustaining Engr	17.3	21.7	39.0
Sustaining Spares	84.6	123.2	207.8
Recertification	4034.0	5284.5	9318.5
Fee	567.5	718.4	1285.9
Program Office Management	393.3	499.2	892.5
Total Operations	6948.9	8819.7	15768.6

Table A-102
Operational Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 15M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (1523 Launches)			
Launch Operations	484.0	720.6	1204.6
Propellants	(83.3)	(268.8)	(352.1)
Launch Area Support	65.3	80.6	145.9
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	7.0	8.1	15.1
Recovery	130.7	130.7	261.4
Transportation	1.2	1.0	2.2
Tech Support & Sustaining Engr	10.4	13.0	23.4
Sustaining Spares	32.9	48.3	81.2
Recertification	470.7	594.8	1065.5
Fee	99.1	120.1	219.2
Program Office Management	78.3	103.3	181.6
Total Operations	1383.6	1824.6	3208.2
Intermediate (1538 Launches)			
Launch Operations	825.5	1134.8	1960.3
Propellants	(84.2)	(271.4)	(355.6)
Launch Area Support	243.2	300.2	543.4
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	15.4	17.9	33.3
Recovery	263.6	263.6	527.2
Transportation	220.3	221.8	442.1
Tech Support & Sustaining Engr	12.5	15.6	28.1
Sustaining Spares	55.5	81.3	136.8
Recertification	5019.8	6279.5	11299.3
Fee	609.5	756.5	1366.0
Program Office Management	436.3	544.7	981.0
Total Operations	7708.3	9622.7	17331.0
Current (1547 Launches)			
Launch Operations	1961.2	2422.6	4383.8
Propellants	(84.7)	(273.0)	(357.7)
Launch Area Support	659.6	814.4	1474.0
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	35.0	40.8	75.8
Recovery	265.3	265.3	530.6
Transportation	232.1	239.3	471.4
Tech Support & Sustaining Engr	17.3	21.7	39.0
Sustaining Spares	106.7	154.3	261.0
Recertification	6905.1	9052.9	15958.0
Fee	961.4	1224.7	2186.1
Program Office Management	669.4	855.0	1524.4
Total Operations	11826.3	15104.2	26930.5

Table A-103
Operational Phase Cost Summary
(Millions of 1969 Dollars)
10 K Concept "L", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (2538 Launches)			
Launch Operations	782.5	1192.1	1974.6
Propellants	(138.9)	(447.9)	(586.8)
Launch Area Support	90.7	112.4	203.1
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	7.9	9.1	17.0
Recovery	216.0	216.0	432.0
Transportation	2.0	1.8	3.8
Tech Support & Sustaining Engr	10.4	13.0	23.4
Sustaining Spares	39.3	57.4	96.7
Recertification	746.4	970.1	1716.5
Fee	154.2	191.0	345.2
Program Office Management	123.2	166.0	289.2
Total Operations	2176.5	2933.0	5109.5
Intermediate (2564 Launches)			
Launch Operations	1342.9	1878.2	3221.1
Propellants	(140.3)	(452.5)	(592.8)
Launch Area Support	337.7	418.7	756.4
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	17.4	20.1	37.5
Recovery	436.0	436.0	872.0
Transportation	367.2	369.4	736.6
Tech Support & Sustaining Engr	12.5	15.6	28.1
Sustaining Spares	66.4	96.7	163.1
Recertification	8098.7	10373.4	18472.1
Fee	974.2	1235.7	2209.9
Program Office Management	699.6	891.0	1590.6
Total Operations	12359.4	15741.8	28101.2
Current (2575 Launches)			
Launch Operations	3174.1	4005.1	7179.2
Propellants	(140.9)	(454.4)	(595.3)
Launch Area Support	915.2	1134.7	2049.9
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	39.7	46.0	85.7
Recovery	438.0	438.0	876.0
Transportation	385.9	398.2	784.1
Tech Support & Sustaining Engr	17.3	21.7	39.0
Sustaining Spares	217.6	183.6	311.2
Recertification	10670.0	13972.7	24642.7
Fee	1481.6	1892.3	3373.9
Program Office Management	1035.8	1326.4	2362.2
Total Operations	18298.4	23432.0	41721.4

Table A-104
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L", 2.5M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (101 Launches)			
Launch Operations	45.9	60.9	106.8
Propellants	(6.6)	(26.8)	(33.4)
Launch Area Support	14.9	17.6	32.5
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	2.9	3.7	6.6
Recovery	11.3	11.3	22.6
Transportation	.2	.2	.4
Tech Support & Sustaining Engr	10.8	13.9	24.7
Sustaining Spares	11.2	18.2	29.4
Recertification	35.7	50.7	86.4
Fee	11.9	14.2	26.1
Program Office Management	8.9	11.7	20.6
Total Operations	157.7	206.4	364.1
Intermediate (102 Launches)			
Launch Operations	73.8	92.1	165.9
Propellants	(6.6)	(27.1)	(33.7)
Launch Area Support	55.2	65.5	120.7
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	6.4	8.0	14.4
Recovery	22.4	22.4	44.8
Transportation	14.6	14.8	29.4
Tech Support & Sustaining Engr	12.9	16.7	29.6
Sustaining Spares	18.9	30.6	49.5
Recertification	344.4	504.1	848.5
Fee	51.2	69.7	120.9
Program Office Management	36.4	49.8	86.2
Total Operations	643.1	880.4	1523.5
Current (105 Launches)			
Launch Operations	187.3	193.6	380.9
Propellants	(6.8)	(27.9)	(34.7)
Launch Area Support	151.2	179.5	330.7
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	14.8	18.5	33.3
Recovery	23.0	23.0	46.0
Transportation	15.9	16.6	32.5
Tech Support & Sustaining Engr	18.0	23.2	41.2
Sustaining Spares	36.3	57.2	93.5
Recertification	717.4	984.8	1702.2
Fee	113.1	144.2	257.3
Program Office Management	77.4	99.2	176.6
Total Operations	1367.8	1753.2	3121.0

Table A-105
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (325 Launches)			
Launch Operations	125.0	193.0	318.0
Propellants	(21.2)	(86.2)	(107.4)
Launch Area Support	26.7	32.9	59.6
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	4.5	5.5	10.0
Recovery	30.1	30.1	60.2
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	10.8	13.9	24.7
Sustaining Spares	19.4	30.6	50.0
Recertification	102.9	146.0	248.9
Fee	27.2	34.0	61.2
Program Office Management	21.1	29.4	50.5
Total Operations	372.0	519.7	891.7
Intermediate (328 Launches)			
Launch Operations	206.2	290.1	496.3
Propellants	(21.4)	(87.0)	(108.4)
Launch Area Support	99.2	122.5	221.7
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	10.0	12.0	22.0
Recovery	60.3	60.3	120.6
Transportation	47.1	47.4	94.5
Tech Support & Sustaining Engr	12.9	16.7	29.6
Sustaining Spares	32.7	51.4	84.1
Recertification	1088.8	1605.8	2694.6
Fee	143.5	201.8	345.3
Program Office Management	102.5	144.9	247.4
Total Operations	1810.0	2559.8	4369.8
Current (332 Launches)			
Launch Operations	499.6	595.5	1095.1
Propellants	(21.6)	(88.1)	(109.7)
Launch Area Support	270.1	333.4	603.5
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	22.8	27.5	50.3
Recovery	61.1	61.1	122.2
Transportation	50.1	51.9	102.0
Tech Support & Sustaining Engr	18.0	23.2	41.2
Sustaining Spares	62.5	96.6	159.1
Recertification	1985.5	2734.7	4720.2
Fee	285.0	373.6	658.6
Program Office Management	196.1	258.7	454.8
Total Operations	3464.0	4569.5	8033.5

Table A-106
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (609 Launches)			
Launch Operations	220.0	358.8	578.8
Propellants	(39.7)	(161.6)	(201.3)
Launch Area Support	38.3	48.0	86.3
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	5.5	6.6	12.1
Recovery	53.9	53.9	107.8
Transportation	.6	.6	1.2
Tech Support & Sustaining Engr	10.8	13.9	24.7
Sustaining Spares	25.0	39.1	64.1
Recertification	201.8	287.9	489.7
Fee	46.6	59.7	106.3
Program Office Management	36.4	52.3	88.7
Total Operations	642.8	924.7	1567.5
Intermediate (615 Launches)			
Launch Operations	367.1	538.8	905.9
Propellants	(40.1)	(163.2)	(203.3)
Launch Area Support	142.7	178.6	321.6
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	12.1	14.5	26.6
Recovery	108.5	108.5	217.0
Transportation	88.1	88.9	177.0
Tech Support & Sustaining Engr	12.9	16.7	29.6
Sustaining Spares	42.2	65.6	107.8
Recertification	2030.7	2962.2	4992.9
Fee	257.5	362.0	619.5
Program Office Management	184.1	260.6	444.7
Total Operations	3252.9	4603.3	7856.2
Current (621 Launches)			
Launch Operations	876.9	1101.3	1978.2
Propellants	(40.4)	(164.8)	(205.2)
Launch Area Support	387.9	485.6	873.5
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	27.7	33.1	60.8
Recovery	109.7	109.7	219.4
Transportation	93.4	96.9	190.3
Tech Support & Sustaining Engr	18.0	23.2	41.2
Sustaining Spares	81.0	123.9	204.9
Recertification	3418.9	4700.4	8119.3
Fee	478.3	631.6	1109.9
Program Office Management	330.3	439.1	769.4
Total Operations	5835.5	7758.1	13593.6

Table A-107
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "L", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (1015 Launches)			
Launch Operations	351.9	594.1	946.0
Propellants	(66.1)	(269.3)	(335.4)
Launch Area Support	52.4	66.1	118.5
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	6.3	7.5	13.8
Recovery	88.0	88.0	176.0
Transportation	.8	.8	1.6
Tech Support & Sustaining Engr	10.8	13.9	24.7
Sustaining Spares	30.4	47.1	77.5
Recertification	376.9	540.4	917.3
Fee	76.7	100.4	177.1
Program Office Management	59.9	87.7	147.6
Total Operations	1058.1	1550.0	2608.1
Intermediate (1025 Launches)			
Launch Operations	591.6	891.6	1483.2
Propellants	(66.8)	(272.0)	(338.8)
Launch Area Support	194.9	245.9	440.8
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	14.0	16.7	30.7
Recovery	177.4	177.4	354.8
Transportation	147.0	148.0	295.0
Tech Support & Sustaining Engr	12.9	16.7	29.6
Sustaining Spares	51.3	79.2	130.5
Recertification	3292.3	4820.0	8112.3
Fee	409.7	580.5	990.2
Program Office Management	293.9	419.0	712.9
Total Operations	5191.9	7401.7	12593.6
Current (1032 Launches)			
Launch Operations	1399.7	1816.0	3215.7
Propellants	(67.2)	(273.9)	(341.1)
Launch Area Support	529.0	667.5	1196.5
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	32.0	38.0	70.0
Recovery	178.7	178.7	357.4
Transportation	155.3	160.8	316.1
Tech Support & Sustaining Engr	18.0	23.2	41.2
Sustaining Spares	98.4	149.6	248.0
Recertification	5285.3	7272.3	12557.6
Fee	730.8	970.6	1701.4
Program Office Management	506.4	677.4	1183.8
Total Operations	8947.0	11967.5	20914.5

Table A-108
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 2.5M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (51 Launches)			
Launch Operations	30.2	35.6	65.8
Propellants	(5.7)	(16.8)	(22.5)
Launch Area Support	11.8	13.5	25.3
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	2.2	2.8	5.0
Recovery	7.1	7.1	14.2
Transportation	.2	.2	.4
Tech Support & Sustaining Engr	11.8	14.9	26.7
Sustaining Spares	8.9	14.9	23.8
Recertification	4.4	5.2	9.6
Fee	6.8	7.4	14.2
Program Office Management	5.2	6.3	11.5
Total Operations	92.5	112.0	204.5
Intermediate (51 Launches)			
Launch Operations	46.2	52.4	98.6
Propellants	(5.7)	(16.8)	(22.5)
Launch Area Support	43.6	50.0	93.6
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	4.8	6.2	11.0
Recovery	13.8	13.8	27.6
Transportation	7.4	7.4	14.8
Tech Support & Sustaining Engr	14.1	17.9	32.0
Sustaining Spares	14.9	25.1	40.0
Recertification	217.8	303.5	521.3
Fee	34.3	44.5	78.8
Program Office Management	24.2	31.7	55.9
Total Operations	428.1	559.3	987.4
Current (53 Launches)			
Launch Operations	117.4	109.7	227.1
Propellants	(5.9)	(17.5)	23.4
Launch Area Support	119.6	137.4	257.0
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	11.3	14.3	25.6
Recovery	14.3	14.3	28.6
Transportation	8.1	8.4	16.5
Tech Support & Sustaining Engr	19.6	24.9	44.5
Sustaining Spares	28.9	46.8	75.7
Recertification	460.5	612.9	1073.4
Fee	76.5	94.2	170.7
Program Office Management	52.2	64.6	116.8
Total Operations	921.5	1140.7	2062.2

Table A-109
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (162 Launches)			
Launch Operations	79.6	111.5	191.1
Propellants	(18.1)	(53.4)	(71.5)
Launch Area Support	19.6	23.5	43.1
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	3.7	4.5	8.2
Recovery	16.4	16.4	32.8
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	11.8	14.9	26.7
Sustaining Spares	16.7	26.9	43.6
Recertification	55.8	77.0	132.8
Fee	17.3	20.9	38.2
Program Office Management	13.5	18.0	31.5
Total Operations	238.7	318.0	556.7
Intermediate (164 Launches)			
Launch Operations	216.1	164.6	290.7
Propellants	(18.4)	(54.1)	(72.5)
Launch Area Support	73.0	86.3	159.3
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	8.1	9.0	17.1
Recovery	32.8	32.8	65.6
Transportation	23.6	23.8	47.4
Tech Support & Sustaining Engr	14.1	17.9	32.0
Sustaining Spares	28.2	42.0	70.2
Recertification	688.3	915.6	1603.9
Fee	92.6	118.8	211.4
Program Office Management	65.6	85.1	150.7
Total Operations	1159.2	1502.6	2661.8
Current (167 Launches)			
Launch Operations	301.6	333.9	635.5
Propellants	(18.7)	(55.1)	(73.8)
Launch Area Support	199.3	239.2	438.5
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	18.5	22.7	31.2
Recovery	33.4	33.4	66.8
Transportation	25.5	26.3	51.8
Tech Support & Sustaining Engr	19.6	24.9	44.5
Sustaining Spares	53.6	84.7	138.3
Recertification	1294.9	1735.0	3029.9
Fee	188.2	239.9	428.1
Program Office Management	128.9	165.2	294.1
Total Operations	2276.8	2918.6	5195.4

Table A-110
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 15M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (304 Launches)			
Launch Operations	139.1	207.7	346.8
Propellants	(34.0)	(100.3)	(134.3)
Launch Area Support	27.5	33.5	61.0
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	4.6	5.6	10.2
Recovery	28.3	28.3	56.6
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	11.8	14.9	26.7
Sustaining Spares	22.2	35.3	57.5
Recertification	121.9	168.4	290.3
Fee	29.7	36.9	66.6
Program Office Management	23.4	32.1	55.5
Total Operations	412.8	567.0	979.8
Intermediate (308 Launches)			
Launch Operations	222.7	306.5	529.2
Propellants	(34.5)	(101.6)	(136.1)
Launch Area Support	102.4	125.0	227.4
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	10.1	12.2	22.3
Recovery	57.0	57.0	114.0
Transportation	44.3	44.7	89.0
Tech Support & Sustaining Engr	14.1	17.9	32.0
Sustaining Spares	37.5	59.3	96.8
Recertification	1256.7	1773.9	3030.6
Fee	161.6	220.0	381.6
Program Office Management	114.8	157.4	272.2
Total Operations	2028.0	2780.8	4808.8
Current (311 Launches)			
Launch Operations	519.7	613.5	1133.2
Propellants	(34.8)	(102.6)	(137.4)
Launch Area Support	278.3	339.9	618.2
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	23.1	27,9	51.0
Recovery	57.6	57.6	115.2
Transportation	47.1	48.9	96.0
Tech Support & Sustaining Engr	19.6	24.9	44.5
Sustaining Spares	71.5	111.3	182.8
Recertification	2256.9	2996.9	5253.8
Fee	314.8	402.5	717.3
Program Office Management	216.1	278.2	494.3
Total Operations	3818.2	4914.8	8733.0

Table A-111
Operational Phase Cost Summary
(Millions of 1969 Dollars)
50 K Concept "L", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (507 Launches)			
Launch Operations	221.6	344.2	565.8
Propellants	(56.8)	(167.3)	(224.1)
Launch Area Support	36.9	45.6	82.5
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	5.4	6.4	11.8
Recovery	45.4	45.4	90.8
Transportation	.5	.5	1.0
Tech Support & Sustaining Engr	11.8	14.9	26.7
Sustaining Spares	27.5	43.3	70.8
Recertification	206.9	287.4	494.3
Fee	45.8	57.9	103.7
Program Office Management	36.3	51.0	87.3
Total Operations	642.0	900.5	1542.5
Intermediate (513 Launches)			
Launch Operations	356.6	506.8	863.4
Propellants	(57.4)	(169.2)	(226.6)
Launch Area Support	137.7	169.8	307.5
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	11.9	14.3	26.2
Recovery	91.4	91.4	182.8
Transportation	73.6	74.2	147.8
Tech Support & Sustaining Engr	14.1	17.9	32.0
Sustaining Spares	46.4	72.7	119.1
Recertification	2085.7	2805.6	4891.3
Fee	260.2	342.5	602.7
Program Office Management	185.1	246.1	431.2
Total Operations	3269.5	4348.0	2617.5
Current (518 Launches)			
Launch Operations	823.2	1012.4	1835.6
Propellants	(58.0)	(170.9)	(228.9)
Launch Area Support	374.3	461.7	836.0
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	27.2	32.6	59.8
Recovery	92.4	92.4	184.8
Transportation	78.4	81.2	159.6
Tech Support & Sustaining Engr	19.6	24.9	44.5
Sustaining Spares	88.6	136.7	225.3
Recertification	3514.7	4668.6	8183.3
Fee	480.3	617.9	1098.2
Program Office Management	330.7	428.5	759.2
Total Operations	5842.8	7570.2	13413.0

A3 Concept "M" Cost Estimate - Concept "M" is the designation used for the two-stage vehicle developed by McDonnell Douglas for the NASA-MSC under Contract NAS9-9204, Schedule II. An important feature of this configuration is that both the orbiter and booster have a fixed wing and tail that provide good subsonic cruise and horizontal landing characteristics similar to conventional aircraft. This vehicle is further enhanced by configuring the vehicle for a high angle of attack during entry. The cost estimates prepared for this configuration are presented in the following paragraphs.

A3.1 Total Program Cost - A total program cost summary is provided for each Concept "M" payload size in Tables A-112 through A-117.

A3.2 Cost Summaries by Phase - The cost estimates for the Concept "M" configuration for RDT&E, Investment and Operational Phases are presented in Tables A-118 through A-144. Inventory requirements for the booster and orbiter are shown respectively in Figures A-7 and A-8.

INVENTORY REQUIREMENTS

Concept M - Booster

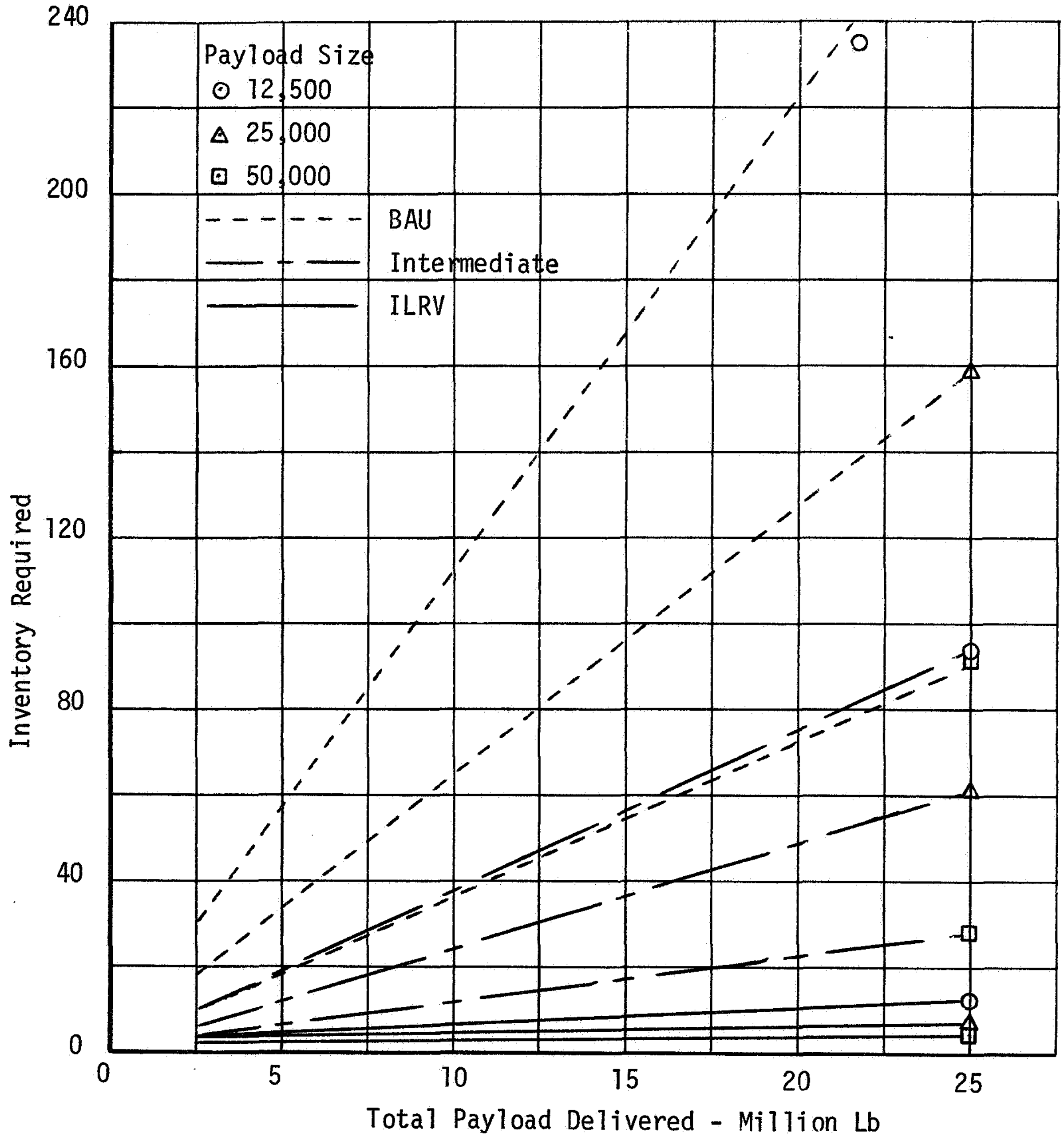


FIGURE A-7

INVENTORY REQUIREMENTS

Concept M - Orbiter

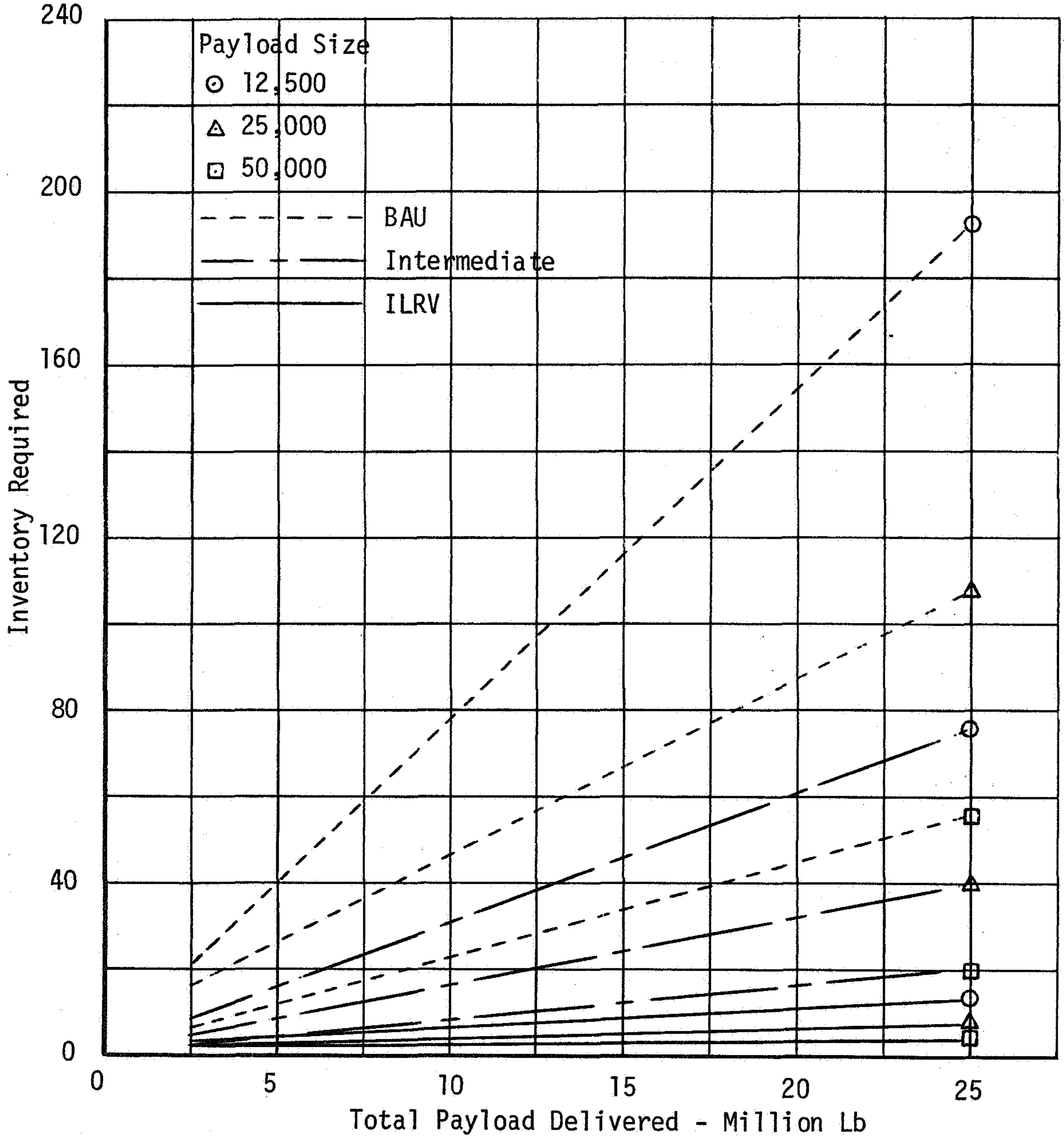


FIGURE A-8

Table A-112
Total Program Cost Summary
12.5 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	106	139	245
Operational Phase	213	245	458
Total Program Cost	3,101	2,383	5,484
Intermediate (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	550	956	1,506
Operational Phase	1,036	1,339	2,375
Total Program Cost	4,368	4,294	8,662
Current (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	1,501	2,844	4,345
Operational Phase	2,061	2,509	4,570
Total Program Cost	6,344	7,352	13,696
Total Payload - 8 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	295	394	689
Operational Phase	584	720	1,304
Total Program Cost	3,661	3,113	6,774
Intermediate (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	1,704	2,844	4,548
Operational Phase	3,164	3,868	7,032
Total Program Cost	7,650	8,711	16,361
Current (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	4,073	7,603	11,676
Operational Phase	5,338	6,625	11,963
Total Program Cost	12,193	16,227	28,420

Table A-113
Total Program Cost Summary
12.5 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 15 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	551	740	1,291
Operational Phase	1,055	1,336	2,391
Total Program Cost	4,388	4,075	8,463
Intermediate (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	3,000	4,979	7,979
Operational Phase	5,702	7,073	12,775
Total Program Cost	11,484	14,051	25,535
Current (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	6,812	12,941	19,753
Operational Phase	9,049	11,287	20,336
Total Program Cost	18,643	26,227	44,870
Total Payload - 25 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	938	1,163	2,101
Operational Phase	1,724	1,336	3,060
Total Program Cost	5,444	4,498	9,942
Intermediate (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	4,668	7,747	12,415
Operational Phase	9,158	11,391	20,549
Total Program Cost	16,608	21,137	37,745
Current (Operational Philosophy)			
Contract Definition Phase	20	10	30
RDT & E Phase	2,762	1,989	4,751
Investment Phase	10,339	19,790	30,129
Operational Phase	13,977	17,494	31,471
Total Program Cost	27,098	39,283	66,381

Table A-114
Total Program Cost Summary
25 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	0	0	0
Operational Phase	163	207	370
Total Program Cost	3,562	3,115	6,677
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	270	765	1,035
Operational Phase	681	923	1,604
Total Program Cost	4,350	4,596	8,946
Current (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	1,151	2,618	3,769
Operational Phase	1,441	1,850	3,291
Total Program Cost	5,991	7,376	13,367
Total Payload - 8 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	139	210	349
Operational Phase	386	522	908
Total Program Cost	3,924	3,640	7,564
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	1,250	2,474	3,724
Operational Phase	1,923	2,727	4,650
Total Program Cost	6,572	8,109	14,681
Current (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	3,280	7,056	10,336
Operational Phase	3,671	4,838	8,509
Total Program Cost	10,350	14,802	25,152

Table A-115
Total Program Cost Summary
25 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 15 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	393	588	981
Operational Phase	667	928	1,595
Total Program Cost	4,459	4,424	8,883
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	2,270	4,364	6,634
Operational Phase	3,453	4,849	8,302
Total Program Cost	9,122	12,121	21,243
Current (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	5,506	11,941	17,447
Operational Phase	6,195	8,222	14,417
Total Program Cost	15,100	23,071	38,171
Total Payload - 25 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	622	935	1,557
Operational Phase	1,100	1,565	2,665
Total Program Cost	5,121	5,408	10,529
Intermediate (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	3,604	6,819	10,423
Operational Phase	3,211	8,016	11,227
Total Program Cost	10,214	17,743	27,957
Current (Operational Philosophy)			
Contract Definition Phase	25	13	38
RDT & E Phase	3,374	2,895	6,269
Investment Phase	8,429	18,248	26,678
Operational Phase	9,508	12,685	22,193
Total Program Cost	21,336	33,841	55,177

Table A-116
Total Program Cost Summary
45 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 2.5 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	0	0	0
Operational Phase	94	127	221
Total Program Cost	3,666	3,978	7,644
Intermediate (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	146	520	666
Operational Phase	437	692	1,129
Total Program Cost	4,155	5,063	9,218
Current (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	650	2,045	2,695
Operational Phase	942	1,407	2,349
Total Program Cost	5,164	7,303	12,467
Total Payload - 8 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	146	270	416
Operational Phase	235	369	604
Total Program Cost	3,953	4,490	8,403
Intermediate (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	765	1,843	2,608
Operational Phase	1,184	1,989	3,173
Total Program Cost	5,521	7,683	13,204
Current (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	2,546	3,833	7,379
Investment Phase	1,996	6,155	8,151
Operational Phase	2,338	3,616	5,954
Total Program Cost	7,906	13,622	21,528

Table A-117
Total Program Cost Summary
45 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Total Payload - 15 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	281	520	801
Operational Phase	424	702	1,126
Total Program Cost	4,277	5,073	9,350
Intermediate (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	1,409	3,570	4,979
Operational Phase	2,081	3,548	5,629
Total Program Cost	7,062	10,969	18,031
Current (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	3,225	10,508	13,733
Operational Phase	3,915	6,134	10,049
Total Program Cost	10,712	20,493	31,205
Total Payload - 25 Million Lb			
ILRV (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	409	758	1,167
Operational Phase	653	1,109	1,762
Total Program Cost	4,634	5,718	10,352
Intermediate (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	2,184	5,658	7,842
Operational Phase	3,303	5,740	9,043
Total Program Cost	9,059	15,249	24,308
Current (Operational Philosophy)			
Contract Definition Phase	26	18	44
RDT & E Phase	3,546	3,833	7,379
Investment Phase	5,290	16,201	21,491
Operational Phase	5,979	9,438	15,417
Total Program Cost	14,841	29,490	44,331

Table A-118
RDT&E, Contract Definition Phase Cost Summary
12.5 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	14	6	20
Project Management	1	1	2
Subtotal	15	7	22
Fee	2	1	3
Subtotal	17	8	25
Program Office Management	3	2	5
Total Contract Definition	20	10	30
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	206	276	482
Power Supply	58	48	106
ECLS	34	13	47
Avionics	446	88	534
Propulsion			
Jet	53	10	63
Orbit Maneuver	28	0	28
Attitude Control	170	27	197
Main Boost	385	95	480
Total Propulsion	636	132	768
Total Subsystems D&D	1380	557	1937
AGE & Special Test Equipment	202	174	376
Launch Facilities	30	20	50
Trainers & Simulators	90	87	177
System Integration			
System Engineering	92	111	203
Wind Tunnel Test	19	19	38
Static Fire Test	39	44	83
Ground Test Hardware	167	215	382
Flight Test Hardware	252	330	582
Flight Test Hardware Spares	19	25	44
Mockups	13	17	30
Horizontal Flight Testing	14	15	29
Vertical Flight Testing	86	68	154
Refurbishment	56	75	131
Total System Integration	757	919	1676
Total Basic RDT&E	2459	1757	4216
Project Management	27	33	60
Subtotal	2486	1790	4276
Fee	249	179	428
Subtotal	2735	1969	4704
Program Office Management	27	20	47
Total RDT&E Phase	2762	1989	4751

Table A-119
RDT&E, Contract Definition Phase Cost Summary
25 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	17	9	26
Project Management	2	1	3
Subtotal	19	10	29
Fee	2	1	3
Subtotal	21	11	32
Program Office Management	4	2	6
Total Contract Definition	25	13	38
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	301	448	749
Power Supply	73	68	141
ECLS	34	13	47
Avionics	446	88	534
Propulsion			
Jet	61	70	131
Orbit Maneuver	35	0	35
Attitude Control	198	34	232
Main Boost	503	140	643
Total Propulsion	797	244	1041
Total Subsystems D&D	1651	861	2512
AGE & Special Test Equipment	231	225	456
Launch Facilities	30	20	50
Trainers & Simulators	115	133	248
System Integration			
System Engineering	125	151	276
Wind Tunnel Test	19	19	38
Static Fire Test	44	54	98
Ground Test Hardware	220	325	545
Flight Test Hardware	335	493	828
Flight Test Hardware Spares	24	35	59
Mockups	18	27	45
Horizontal Flight Testing	19	23	42
Vertical Flight Testing	99	84	183
Refurbishment	71	109	180
Total System Integration	974	1320	2294
Total Basic RDT&E	3001	2559	5560
Project Management	36	46	82
Subtotal	3037	2605	5642
Fee	304	261	565
Subtotal	3341	2866	6207
Program Office Management	33	29	62
Total RDT&E Phase	3374	2895	6269

Table A-120
RDT&E, Contract Definition Phase Cost Summary
45 K Concept "M" (Millions of 1969 Dollars)

	ORBITER	BOOSTER	TOTAL
Contract Definition Phase			
Basic Cost	18	13	31
Project Management	2	1	3
Subtotal	20	14	34
Fee	2	1	3
Subtotal	22	15	37
Program Office Management	4	3	7
Total Contract Definition	26	18	44
RDT&E Phase			
Subsystems Design & Development			
Thermal/Structure	310	598	908
Power Supply	73	81	154
ECLS	34	13	47
Avionics	446	88	534
Propulsion			
Jet	71	97	168
Orbit Maneuver	37	-	37
Attitude Control	207	224	431
Main Boost	576	172	748
Total Propulsion	891	493	1384
Total Subsystems D&D	1754	1273	3027
AGE & Special Test Equipment	242	272	514
Launch Facilities	30	20	50
Trainers & Simulators	118	170	288
System Integration			
System Engineering	129	179	308
Wind Tunnel Test	19	19	38
Static Fire Test	47	64	111
Ground Test Hardware	229	420	649
Flight Test Hardware	348	634	982
Flight Test Hardware Spares	25	45	70
Mockups	19	35	54
Horizontal Flight Testing	20	29	49
Vertical Flight Testing	101	95	196
Refurbishment	74	138	212
Total System Integration	1011	1658	2669
Total Basic RDT&E	3155	3393	6548
Project Management	37	55	92
Subtotal	3192	3448	6640
Fee	319	345	664
Subtotal	3511	3793	7304
Program Office Management	35	40	75
Total RDT&E Phase	3546	3833	7379

Table A-121
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M",2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	28	43	71
Power Supply	6	5	11
ECLS	2	1	3
Avionics	17	12	29
Propulsion	13	30	43
Final Assembly & Checkout	8	9	17
Sustaining Engineering	12	14	26
Sustaining Tooling	4	5	9
Initial Spares	4	5	9
Project Management	1	1	2
Fee	10	13	23
Total	105	138	243
Program Office Management	1	1	2
Total Cost	106	139	245
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	151	296	447
Power Supply	33	32	65
ECLS	11	4	15
Avionics	90	88	178
Propulsion	71	221	292
Final Assembly & Checkout	44	62	106
Sustaining Engineering	51	79	130
Sustaining Tooling	17	31	48
Initial Spares	22	40	62
Project Management	5	8	13
Fee	50	86	136
Total	545	947	1492
Program Office Management	5	9	14
Total Cost	550	956	1506
Quantity of Vehicles	6	8	14
Current Philosophy			
Thermal/Structure	419	884	1303
Power Supply	89	93	182
ECLS	30	13	43
Avionics	254	267	521
Propulsion	209	718	927
Final Assembly & Checkout	117	178	295
Sustaining Engineering	114	181	295
Sustaining Tooling	44	81	125
Initial Spares	64	127	191
Project Management	11	18	29
Fee	135	256	391
Total	1486	2816	4302
Program Office Management	15	28	43
Total Cost	1501	2844	4345
Quantity of Vehicles	19	28	47

Table A-122
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	80	121	201
Power Supply	17	13	30
ECLS	6	2	8
Avionics	47	35	82
Propulsion	37	87	124
Final Assembly & Checkout	23	26	49
Sustaining Engineering	30	37	67
Sustaining Tooling	10	14	24
Initial Spares	12	16	28
Project Management	3	4	7
Fee	27	35	62
Total	292	390	682
Program Office Management	3	4	7
Total Cost	295	394	689
Quantity of Vehicles	3	3	6
Intermediate Philosophy			
Thermal/Structure	476	884	1360
Power Supply	101	93	194
ECLS	34	13	47
Avionics	290	267	557
Propulsion	240	718	958
Final Assembly & Checkout	132	178	310
Sustaining Engineering	126	181	307
Sustaining Tooling	49	81	130
Initial Spares	73	127	200
Project Management	13	18	31
Fee	153	256	409
Total	1687	2816	4503
Program Office Management	17	28	45
Total Cost	1704	2844	4548
Quantity of Vehicles	22	28	50
Current Philosophy			
Thermal/Structure	1149	2346	3495
Power Supply	240	241	481
ECLS	82	35	117
Avionics	714	726	1440
Propulsion	624	2097	2721
Final Assembly & Checkout	307	452	759
Sustaining Engineering	237	361	598
Sustaining Tooling	105	187	292
Initial Spares	184	363	547
Project Management	24	36	60
Fee	367	684	1051
Total	4033	7528	11,561
Program Office Management	40	75	115
Total Cost	4073	7603	11,676
Quantity of Vehicles	62	89	151

Table A-123
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M" 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	151	229	380
Power Supply	33	25	58
ECLS	11	3	14
Avionics	90	67	157
Propulsion	71	168	239
Final Assembly & Checkout	44	48	92
Sustaining Engineering	51	64	115
Sustaining Tooling	18	25	43
Initial Spares	22	31	53
Project Management	5	6	11
Fee	50	67	117
Total	546	733	1279
Program Office Management	5	7	12
Total Cost	551	740	1291
Quantity of Vehicles	6	6	12
Intermediate Philosophy			
Thermal/Structure	844	1543	2387
Power Supply	177	161	338
ECLS	60	23	83
Avionics	520	472	992
Propulsion	446	1321	1767
Final Assembly & Checkout	229	303	532
Sustaining Engineering	191	270	461
Sustaining Tooling	81	131	212
Initial Spares	133	231	364
Project Management	19	27	46
Fee	270	448	718
Total	2970	4930	7900
Program Office Management	30	49	79
Total Cost	3000	4979	7979
Quantity of Vehicles	43	54	97
Current Philosophy			
Thermal/Structure	1929	3963	5892
Power Supply	399	400	799
ECLS	138	59	197
Avionics	1213	1243	2456
Propulsion	1100	3746	4846
Final Assembly & Checkout	503	743	1246
Sustaining Engineering	337	514	851
Sustaining Tooling	162	291	453
Initial Spares	317	638	955
Project Management	34	51	85
Fee	613	1165	1778
Total	6745	12,813	19,558
Program Office Management	67	128	195
Total Cost	6812	12,941	19,753
Quantity of Vehicles	115	167	282

Table A-124
Investment Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	260	361	621
Power Supply	56	39	95
ECLS	18	5	23
Avionics	156	107	263
Propulsion	126	273	399
Final Assembly & Checkout	74	75	149
Sustaining Engineering	79	92	171
Sustaining Tooling	29	37	66
Initial Spares	39	49	88
Project Management	8	9	17
Fee	84	105	189
Total	929	1152	2081
Program Office Management	9	11	20
Total Cost	938	1163	2101
Quantity of Vehicles	11	10	21
Intermediate Philosophy			
Thermal/Structure	1319	2390	3709
Power Supply	275	245	520
ECLS	94	35	129
Avionics	822	740	1562
Propulsion	726	2140	2866
Final Assembly & Checkout	350	460	810
Sustaining Engineering	260	366	626
Sustaining Tooling	118	190	308
Initial Spares	212	370	582
Project Management	26	37	63
Fee	420	697	1117
Total	4622	7670	12,292
Program Office Management	46	77	123
Total Cost	4668	7747	12,415
Quantity of Vehicles	73	91	164
Current Philosophy			
Thermal/Structure	2930	6009	8939
Power Supply	602	598	1200
ECLS	210	91	301
Avionics	1863	1905	3768
Propulsion	1742	5949	7691
Final Assembly & Checkout	747	1101	1848
Sustaining Engineering	446	677	1123
Sustaining Tooling	230	413	643
Initial Spares	493	1002	1495
Project Management	44	68	112
Fee	930	1781	2711
Total	10,237	19,594	29,831
Program Office Management	102	196	298
Total Cost	10,339	19,790	30,129
Quantity of Vehicles	190	276	466

Table A-125
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure			
Power Supply			
ECLS			
Avionics			
Propulsion			
Final Assembly & Checkout			
Sustaining Engineering			
Sustaining Tooling			
Initial Spares			
Project Management			
Fee			
Total			
Program Office Management			
Total Cost			
Quantity of Vehicles	-0-	-0-	-0-
Intermediate Philosophy			
Thermal/Structure	87	261	348
Power Supply	14	22	36
ECLS	4	2	6
Avionics	32	46	78
Propulsion	36	176	212
Final Assembly & Checkout	21	49	70
Sustaining Engineering	26	67	93
Sustaining Tooling	10	29	39
Initial Spares	10	29	39
Project Management	3	7	10
Fee	24	69	93
Total	267	757	1024
Program Office Management	3	8	11
Total Cost	270	765	1035
Quantity of Vehicles	2	4	6
Current Philosophy			
Thermal/Structure	378	896	1274
Power Supply	59	73	132
ECLS	17	9	26
Avionics	144	163	307
Propulsion	166	656	822
Final Assembly & Checkout	87	164	251
Sustaining Engineering	92	181	273
Sustaining Tooling	40	89	129
Initial Spares	45	107	152
Project Management	9	18	27
Fee	103	236	339
Total	1140	2592	3732
Program Office Management	11	26	37
Total Cost	1151	2618	3769
Quantity of Vehicles	10	16	26

Table A-126
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	45	71	116
Power Supply	7	6	13
ECLS	2	1	3
Avionics	17	12	29
Propulsion	18	46	64
Final Assembly & Checkout	11	14	25
Sustaining Engineering	14	21	35
Sustaining Tooling	5	8	13
Initial Spares	5	8	13
Project Management	1	2	3
Fee	13	19	32
Total	138	208	346
Program Office Management	1	2	3
Total Cost	139	210	349
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	411	847	1258
Power Supply	64	69	133
ECLS	18	8	26
Avionics	156	154	310
Propulsion	182	617	799
Final Assembly & Checkout	94	156	250
Sustaining Engineering	98	173	271
Sustaining Tooling	43	85	128
Initial Spares	49	101	150
Project Management	10	17	27
Fee	113	223	336
Total	1238	2450	3688
Program Office Management	12	24	36
Total Cost	1250	2474	3724
Quantity of Vehicles	11	15	26
Current Philosophy			
Thermal/Structure	1092	2407	3499
Power Supply	167	191	358
ECLS	49	24	73
Avionics	424	449	873
Propulsion	519	1926	2445
Final Assembly & Checkout	241	426	667
Sustaining Engineering	204	373	577
Sustaining Tooling	101	210	311
Initial Spares	136	308	444
Project Management	20	37	57
Fee	295	635	930
Total	3248	6986	10,234
Program Office Management	32	70	102
Total Cost	3280	7056	10,336
Quantity of Vehicles	34	51	85

Table A-127
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M",15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	127	200	327
Power Supply	20	17	37
ECLS	6	2	8
Avionics	47	35	82
Propulsion	53	134	187
Final Assembly & Checkout	30	38	68
Sustaining Engineering	37	53	90
Sustaining Tooling	15	23	38
Initial Spares	15	22	37
Project Management	4	5	9
Fee	35	53	88
Total	389	582	971
Program Office Management	4	6	10
Total Cost	393	588	981
Quantity of Vehicles	3	3	6
Intermediate Philosophy			
Thermal/Structure	752	1493	2245
Power Supply	116	120	236
ECLS	34	15	49
Avionics	290	275	565
Propulsion	347	1142	1489
Final Assembly & Checkout	168	269	437
Sustaining Engineering	156	265	421
Sustaining Tooling	73	139	212
Initial Spares	92	184	276
Project Management	16	26	42
Fee	204	393	597
Total	2248	4321	6569
Program Office Management	22	43	65
Total Cost	2270	4364	6634
Quantity of Vehicles	22	29	51
Current Philosophy			
Thermal/Structure	1839	4049	5888
Power Supply	279	317	596
ECLS	83	40	123
Avionics	724	767	1491
Propulsion	915	3420	4335
Final Assembly & Checkout	396	700	1096
Sustaining Engineering	296	535	831
Sustaining Tooling	158	326	484
Initial Spares	236	541	777
Project Management	30	53	83
Fee	496	1075	1571
Total	5452	11,823	17,275
Program Office Management	54	118	172
Total Cost	5506	11,941	17,447
Quantity of Vehicles	63	95	158

Table A-128
Investment Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	203	319	522
Power Supply	32	27	59
ECLS	9	3	12
Avionics	76	57	133
Propulsion	86	218	304
Final Assembly & Checkout	47	60	107
Sustaining Engineering	55	79	134
Sustaining Tooling	23	35	58
Initial Spares	24	36	60
Project Management	5	8	13
Fee	56	84	140
Total	616	926	1542
Program Office Management	6	9	15
Total Cost	622	935	1557
Quantity of Vehicles	5	5	10
Intermediate Philosophy			
Thermal/Structure	1200	2327	3527
Power Supply	183	185	368
ECLS	54	23	77
Avionics	467	434	901
Propulsion	575	1856	2431
Final Assembly & Checkout	263	412	675
Sustaining Engineering	219	364	583
Sustaining Tooling	110	204	314
Initial Spares	151	297	448
Project Management	22	36	58
Fee	324	614	938
Total	3568	6752	10,320
Program Office Management	36	67	103
Total Cost	3604	6819	10,423
Quantity of Vehicles	38	49	87
Current Philosophy			
Thermal/Structure	2820	6144	8964
Power Supply	424	475	899
ECLS	128	61	189
Avionics	1123	1179	2302
Propulsion	1461	5431	6892
Final Assembly & Checkout	595	1041	1636
Sustaining Engineering	397	709	1106
Sustaining Tooling	227	464	691
Initial Spares	372	851	1223
Project Management	40	71	111
Fee	759	1642	2401
Total	8346	18,068	26,414
Program Office Management	83	180	264
Total Cost	8429	18,248	26,678
Quantity of Vehicles	105	157	262

Table A-129
Investment Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M",2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure			
Power Supply			
ECLS			
Avionics			
Propulsion			
Final Assembly & Checkout			
Sustaining Engineering			
Sustaining Tooling			
Initial Spares			
Project Management			
Fee			
Total			
Program Office Management			
Total Cost			
Quantity of Vehicles	-0-	-0-	-0-
Intermediate Philosophy			
Thermal/Structure	46	186	232
Power Supply	7	13	20
ECLS	2	1	3
Avionics	17	24	41
Propulsion	21	121	142
Final Assembly & Checkout	11	33	44
Sustaining Engineering	15	45	60
Sustaining Tooling	6	21	27
Initial Spares	5	19	24
Project Management	2	5	7
Fee	13	47	60
Total	145	515	660
Program Office Management	1	5	6
Total Cost	146	520	666
Quantity of Vehicles	1	2	3
Current Philosophy			
Thermal/Structure	207	735	942
Power Supply	32	50	82
ECLS	9	5	14
Avionics	76	97	173
Propulsion	100	511	611
Final Assembly & Checkout	49	126	175
Sustaining Engineering	58	146	204
Sustaining Tooling	23	76	99
Initial Spares	25	80	105
Project Management	6	15	21
Fee	59	184	243
Total	644	2025	2669
Program Office Management	6	20	26
Total Cost	650	2045	2695
Quantity of Vehicles	5	9	14

Table A-130
Investment Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	46	96	142
Power Supply	7	7	14
ECLS	2	1	3
Avionics	17	12	29
Propulsion	21	61	82
Final Assembly & Checkout	11	17	28
Sustaining Engineering	15	25	40
Sustaining Tooling	6	11	17
Initial Spares	5	10	15
Project Management	2	3	5
Fee	13	24	37
Total	145	267	412
Program Office Management	1	3	4
Total Cost	146	270	416
Quantity of Vehicles	1	1	2
Intermediate Philosophy			
Thermal/Structure	244	662	906
Power Supply	37	45	82
ECLS	11	5	16
Avionics	90	88	178
Propulsion	119	457	576
Final Assembly & Checkout	58	114	172
Sustaining Engineering	66	134	200
Sustaining Tooling	27	69	96
Initial Spares	29	72	101
Project Management	7	13	20
Fee	69	166	235
Total	757	1825	2582
Program Office Management	8	18	26
Total Cost	765	1843	2608
Quantity of Vehicles	6	8	14
Current Philosophy			
Thermal/Structure	645	2205	2850
Power Supply	98	147	245
ECLS	28	16	44
Avionics	243	300	543
Propulsion	332	1676	2008
Final Assembly & Checkout	148	365	513
Sustaining Engineering	142	338	480
Sustaining Tooling	65	200	265
Initial Spares	81	259	340
Project Management	14	34	48
Fee	180	554	734
Total	1976	6094	8070
Program Office Management	20	61	81
Total Cost	1996	6155	8151
Quantity of Vehicles	18	32	50

Table A-131
Investment Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	89	186	275
Power Supply	14	13	27
ECLS	4	1	5
Avionics	32	24	56
Propulsion	41	121	162
Final Assembly & Checkout	21	33	54
Sustaining Engineering	28	45	73
Sustaining Tooling	11	21	32
Initial Spares	10	19	29
Project Management	3	5	8
Fee	25	47	72
Total	278	515	793
Program Office Management	3	5	8
Total Cost	281	520	801
Quantity of Vehicles	2	2	4
Intermediate Philosophy			
Thermal/Structure	453	1282	1735
Power Supply	69	86	155
ECLS	20	9	29
Avionics	169	172	341
Propulsion	228	930	1158
Final Assembly & Checkout	105	216	321
Sustaining Engineering	109	226	335
Sustaining Tooling	48	125	173
Initial Spares	56	145	201
Project Management	11	23	34
Fee	127	321	448
Total	1395	3535	4930
Program Office Management	14	35	49
Total Cost	1409	3570	4979
Quantity of Vehicles	12	17	29
Current Philosophy			
Thermal/Structure	1114	3748	4862
Power Supply	167	246	413
ECLS	49	27	76
Avionics	242	517	759
Propulsion	599	2999	3598
Final Assembly & Checkout	250	606	856
Sustaining Engineering	213	492	705
Sustaining Tooling	104	315	419
Initial Spares	144	459	603
Project Management	21	49	70
Fee	290	946	1236
Total	3193	10,404	13,597
Program Office Management	32	104	136
Total Cost	3225	10,508	13,733
Quantity of Vehicles	34	60	94

Table A-132
Investment Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV Philosophy			
Thermal/Structure	130	271	401
Power Supply	20	19	39
ECLS	6	2	8
Avionics	47	35	82
Propulsion	61	179	240
Final Assembly & Checkout	31	48	79
Sustaining Engineering	39	63	102
Sustaining Tooling	15	31	46
Initial Spares	15	28	43
Project Management	4	6	10
Fee	37	68	105
Total	405	750	1155
Program Office Management	4	8	12
Total Cost	409	758	1167
Quantity of Vehicles	3	3	6
Intermediate Philosophy			
Thermal/Structure	707	2028	2735
Power Supply	107	135	242
ECLS	31	15	46
Avionics	266	275	541
Propulsion	367	1530	1897
Final Assembly & Checkout	162	337	499
Sustaining Engineering	152	318	470
Sustaining Tooling	70	186	256
Initial Spares	89	237	326
Project Management	15	32	47
Fee	197	509	706
Total	2163	5602	7765
Program Office Management	21	56	77
Total Cost	2184	5658	7842
Quantity of Vehicles	20	29	49
Current Philosophy			
Thermal/Structure	1724	5742	7466
Power Supply	256	372	628
ECLS	76	42	118
Avionics	664	802	1466
Propulsion	964	4804	5768
Final Assembly & Checkout	380	911	1291
Sustaining Engineering	290	661	951
Sustaining Tooling	151	453	604
Initial Spares	228	730	958
Project Management	29	66	95
Fee	476	1458	1934
Total	5238	16,041	21,279
Program Office Management	52	160	212
Total Cost	5290	16,201	21,491
Quantity of Vehicles	57	100	157

Table A-133
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (203 Launches)			
Launch Operations	72.4	78.8	151.2
Propellants	(6.6)	(23.6)	(30.2)
Launch Area Support	19.7	21.8	41.5
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	3.7	4.2	7.9
Recovery	19.8	19.8	39.6
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	10.0	11.4	21.4
Sustaining Spares	13.4	18.7	32.1
Recertification	41.9	55.2	97.1
Fee	15.9	17.1	33.0
Program Office Management	12.1	13.9	26.0
Total Operations	213.2	245.4	458.6
Intermediate (205 Launches)			
Launch Operations	121.5	128.9	250.4
Propellants	(6.6)	(23.8)	(30.4)
Launch Area Support	73.3	81.2	154.5
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	8.2	9.5	17.7
Recovery	39.7	39.7	79.4
Transportation	29.4	29.6	59.0
Tech Support & Sustaining Engr	12.0	13.6	25.6
Sustaining Spares	22.6	31.5	54.1
Recertification	581.6	815.8	1397.4
Fee	81.9	106.4	188.3
Program Office Management	58.6	75.8	134.4
Total Operations	1035.7	1338.8	2374.5
Current (208 Launches)			
Launch Operations	307.7	287.5	595.2
Propellants	(6.7)	(24.2)	(30.9)
Launch Area Support	199.6	221.1	420.7
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	18.8	21.7	40.5
Recovery	40.3	40.3	80.6
Transportation	31.3	32.4	63.7
Tech Support & Sustaining Engr	16.7	19.0	35.7
Sustaining Spares	43.3	59.4	102.7
Recertification	1103.3	1466.2	2569.5
Fee	169.6	206.4	377.0
Program Office Management	116.6	142.0	258.6
Total Operations	2060.8	2509.4	4570.2

Table A-134
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (650 Launches)			
Launch Operations	200.5	247.6	448.1
Propellants	(21.1)	(75.5)	(96.6)
Launch Area Support	37.5	42.1	79.6
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	5.4	6.1	11.5
Recovery	57.4	57.4	114.8
Transportation	.6	.6	1.2
Tech Support & Sustaining Engr	10.0	11.4	21.4
Sustaining Spares	21.9	29.9	51.8
Recertification	171.0	230.4	401.4
Fee	42.9	49.6	92.5
Program Office Management	33.1	40.7	73.8
Total Operations	584.3	719.7	1304.0
Intermediate (656 Launches)			
Launch Operations	346.1	403.8	749.9
Propellants	(21.2)	(76.2)	(97.5)
Launch Area Support	139.4	156.5	295.9
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	12.0	13.5	25.5
Recovery	115.4	115.4	230.8
Transportation	93.9	94.6	188.5
Tech Support & Sustaining Engr	12.0	13.7	25.7
Sustaining Spares	36.9	50.3	87.2
Recertification	1972.1	2488.3	4160.4
Fee	250.4	305.7	556.1
Program Office Management	179.1	218.9	398.0
Total Operations	3164.4	3867.6	7032.0
Current (662 Launches)			
Launch Operations	852.8	893.4	1746.2
Propellants	(21.4)	(77.0)	(98.4)
Launch Area Support	378.9	425.2	804.1
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	27.4	30.8	58.2
Recovery	116.6	116.6	233.2
Transportation	99.4	102.5	201.9
Tech Support & Sustaining Engr	16.7	79.0	35.7
Sustaining Spares	70.9	95.3	166.2
Recertification	3023.4	4012.3	7035.7
Fee	436.2	541.2	977.4
Program Office Management	302.1	375.0	677.1
Total Operations	5337.7	6624.6	11962.3

Table A-135
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (1218 Launches)			
Launch Operations	355.6	459.3	814.9
Propellants	(39.4)	(141.5)	(180.9)
Launch Area Support	55.0	61.9	116.9
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	6.4	7.2	13.6
Recovery	105.1	105.1	210.2
Transportation	.9	.9	1.8
Tech Support & Sustaining Engr	10.0	11.4	21.4
Sustaining Spares	27.7	37.5	65.2
Recertification	353.5	480.8	834.3
Fee	77.3	92.1	169.4
Program Office Management	59.7	75.6	135.3
Total Operations	1055.2	1335.9	2391.1
Intermediate (1231 Launches)			
Launch Operations	621.8	750.2	1372.0
Propellants	(39.9)	(143.0)	(182.9)
Launch Area Support	204.7	230.7	435.4
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	14.2	15.9	30.1
Recovery	212.0	212.0	424.0
Transportation	176.3	177.5	353.8
Tech Support & Sustaining Engr	12.0	13.7	25.7
Sustaining Spares	46.8	63.2	110.0
Recertification	3634.6	4644.6	8279.2
Fee	450.1	558.2	1008.3
Program Office Management	322.8	400.4	723.2
Total Operations	5702.2	7073.1	12775.3
Current (1238 Launches)			
Launch Operations	1515.9	1654.1	3170.0
Propellants	(40.1)	(143.8)	(183.9)
Launch Area Support	555.1	625.6	1180.7
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	32.5	36.3	68.8
Recovery	213.3	213.3	426.6
Transportation	185.5	191.5	377.0
Tech Support & Sustaining Engr	16.7	19.0	35.7
Sustaining Spares	89.9	119.8	209.7
Recertification	5178.5	6856.8	12035.3
Fee	736.2	918.1	1654.3
Program Office Management	512.2	638.9	1151.1
Total Operations	9049.2	11286.8	20336.0

Table A-136
Operational Phase Cost Summary
(Millions of 1969 Dollars)
12.5 K Concept "M", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (2030 Launches)			
Launch Operations	571.6	459.3	1030.9
Propellants	(65.7)	(141.5)	(207.2)
Launch Area Support	75.9	61.9	137.8
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	7.3	7.2	14.5
Recovery	173.3	105.1	278.4
Transportation	1.5	.9	2.4
Tech Support & Sustaining Engr	10.0	11.4	21.4
Sustaining Spares	33.2	37.6	70.8
Recertification	623.5	480.8	1104.3
Fee	126.0	92.1	218.1
Program Office Management	97.6	75.6	173.2
Total Operations	1724.0	1335.9	3059.9
Intermediate (2051 Launches)			
Launch Operations	1007.1	1240.1	2247.2
Propellants	(66.4)	(238.3)	(304.7)
Launch Area Support	282.8	319.5	602.3
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	16.2	18.1	34.3
Recovery	349.8	349.8	699.6
Transportation	293.7	295.8	589.5
Tech Support & Sustaining Engr	12.0	13.7	25.7
Sustaining Spares	56.1	75.3	131.4
Recertification	5894.5	7530.5	13425.0
Fee	720.9	896.6	1617.5
Program Office Management	518.4	644.8	1163.2
Total Operations	9158.5	11390.8	20549.3
Current (2061 Launches)			
Launch Operations	2443.7	2733.7	5177.4
Propellants	(66.7)	(239.5)	(306.2)
Launch Area Support	766.7	866.1	1632.8
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	37.0	41.1	78.1
Recovery	351.6	351.6	703.2
Transportation	308.6	318.5	627.1
Tech Support & Sustaining Engr	16.7	19.0	35.7
Sustaining Spares	107.8	143.1	250.9
Recertification	8007.3	10600.1	18607.4
Fee	1132.6	1417.7	2550.3
Program Office Management	791.1	990.3	1781.4
Total Operations	13976.5	17494.5	31471.0

Table A-137
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (101 Launches)			
Launch Operations	46.4	57.1	103.5
Propellants	(5.3)	(23.1)	(28.4)
Launch Area Support	15.4	17.6	33.0
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	3.0	3.6	6.6
Recovery	11.3	11.3	22.6
Transportation	.2	.2	.4
Tech Support & Sustaining Engr	11.5	13.8	25.3
Sustaining Spares	11.9	18.8	30.7
Recertification	37.7	54.2	91.9
Fee	12.5	14.6	27.1
Program Office Management	9.2	11.7	20.9
Total Operations	163.0	207.0	370.0
Intermediate (102 Launches)			
Launch Operations	75.8	88.1	163.9
Propellants	(5.3)	(23.4)	(28.7)
Launch Area Support	57.3	65.3	122.6
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	6.6	8.0	14.6
Recovery	22.4	22.4	44.8
Transportation	14.6	14.9	29.5
Tech Support & Sustaining Engr	13.8	16.6	30.4
Sustaining Spares	20.1	31.5	51.6
Recertification	370.4	544.0	914.4
Fee	54.5	73.7	128.2
Program Office Management	38.5	52.3	90.8
Total Operations	680.9	923.4	1604.3
Current (105 Launches)			
Launch Operations	194.3	189.0	383.3
Propellants	(5.5)	(24.1)	(29.6)
Launch Area Support	156.8	179.0	335.8
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	15.2	18.4	33.6
Recovery	23.0	23.0	46.0
Transportation	16.0	16.7	32.7
Tech Support & Sustaining Engr	19.1	23.1	42.2
Sustaining Spares	38.4	58.8	97.2
Recertification	763.8	1070.8	1834.6
Fee	119.6	152.8	272.4
Program Office Management	81.6	104.7	186.3
Total Operations	1441.2	1849.7	3290.9

Table A-138
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (325 Launches)			
Launch Operations	126.3	180.8	307.1
Propellants	(17.1)	(74.5)	(91.6)
Launch Area Support	28.0	32.8	60.8
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	4.6	5.5	10.1
Recovery	30.1	30.1	60.2
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	11.5	13.8	25.3
Sustaining Spares	20.7	31.6	52.3
Recertification	109.4	158.0	267.4
Fee	28.7	35.2	63.9
Program Office Management	21.8	29.2	51.0
Total Operations	385.6	521.7	907.3
Intermediate (328 Launches)			
Launch Operations	212.4	277.3	489.7
Propellants	(17.3)	(75.2)	(92.5)
Launch Area Support	104.2	122.0	226.2
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	10.1	12.0	22.1
Recovery	60.3	60.3	120.6
Transportation	47.1	47.5	94.6
Tech Support & Sustaining Engr	13.8	16.6	30.4
Sustaining Spares	34.8	53.0	87.8
Recertification	1171.4	1759.6	2931.0
Fee	153.6	217.2	370.8
Program Office Management	108.9	154.3	263.2
Total Operations	1923.5	2726.8	4650.3
Current (332 Launches)			
Launch Operations	521.0	581.1	1102.1
Propellants	(17.5)	(76.1)	(93.6)
Launch Area Support	283.5	332.2	615.7
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	23.3	27.4	50.7
Recovery	61.1	61.1	122.2
Transportation	50.3	52.2	102.5
Tech Support & Sustaining Engr	19.1	23.0	32.1
Sustaining Spares	66.5	99.4	165.9
Recertification	2121.9	2976.2	5098.1
Fee	303.1	397.7	700.8
Program Office Management	207.8	273.8	481.6
Total Operations	3671.1	4837.6	8508.7

Table A-139
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (609 Launches)			
Launch Operations	222.9	335.8	558.7
Propellants	(32.6)	(139.6)	(172.2)
Launch Area Support	40.4	47.8	88.2
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	5.6	6.5	12.1
Recovery	53.9	53.9	107.8
Transportation	.6	.6	1.2
Tech Support & Sustaining Engr	11.5	13.8	25.3
Sustaining Spares	26.7	40.4	67.1
Recertification	214.0	310.5	524.5
Fee	49.3	61.9	111.2
Program Office Management	37.7	52.5	90.2
Total Operations	666.6	927.8	1594.4
Intermediate (615 Launches)			
Launch Operations	378.4	514.8	893.2
Propellants	(32.3)	(140.9)	(173.2)
Launch Area Support	150.5	177.9	328.4
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	12.5	14.5	27.0
Recovery	108.5	108.5	217.0
Transportation	88.2	89.0	197.2
Tech Support & Sustaining Engr	13.8	16.6	30.4
Sustaining Spares	45.0	67.7	112.7
Recertification	2178.8	3193.7	5372.5
Fee	275.3	385.1	660.4
Program Office Management	195.5	274.5	470.0
Total Operations	3453.2	4849.2	8302.4
Current (621 Launches)			
Launch Operations	916.5	1074.5	1991.0
Propellants	(32.7)	(142.3)	(175.0)
Launch Area Support	409.1	483.6	892.7
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	28.4	33.0	61.4
Recovery	109.7	109.7	119.4
Transportation	93.8	97.5	191.3
Tech Support & Sustaining Engr	19.1	23.1	42.2
Sustaining Spares	86.1	127.5	213.6
Recertification	3658.4	5121.2	8779.6
Fee	509.8	673.4	1183.2
Program Office Management	350.7	465.4	816.1
Total Operations	6194.9	8222.3	14417.2

Table A-140
Operational Phase Cost Summary
(Millions of 1969 Dollars)
25 K Concept "M", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (1015 Launches)			
Launch Operations	355.6	555.9	911.5
Propellants	(53.4)	(232.6)	(286.0)
Launch Area Support	55.4	65.8	121.2
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	6.5	7.5	14.0
Recovery	88.0	88.0	176.0
Transportation	.8	.8	1.6
Tech Support & Sustaining Engr	11.5	13.8	25.3
Sustaining Spares	32.4	48.7	81.1
Recertification	401.7	586.5	988.2
Fee	81.4	105.0	186.4
Program Office Management	62.2	88.6	150.8
Total Operations	1099.6	1564.5	2664.1
Intermediate (1025 Launches)			
Launch Operations	552.6	851.7	1404.3
Propellants	(53.9)	(234.9)	(288.8)
Launch Area Support	143.7	244.9	388.6
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	12.1	16.6	28.7
Recovery	101.0	177.4	278.4
Transportation	81.8	148.3	230.1
Tech Support & Sustaining Engr	13.8	16.6	30.4
Sustaining Spares	43.7	81.7	125.4
Recertification	2017.3	5381.6	7398.9
Fee	256.0	636.5	892.5
Program Office Management	181.7	453.7	635.4
Total Operations	3410.5	8015.9	11426.4
Current (1032 Launches)			
Launch Operations	1464.8	1771.6	3236.4
Propellants	(54.3)	(236.5)	(290.8)
Launch Area Support	559.4	664.8	1224.2
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	33.0	37.9	70.9
Recovery	178.7	178.7	357.4
Transportation	155.8	161.7	317.5
Tech Support & Sustaining Engr	19.1	23.1	42.2
Sustaining Spares	104.6	154.0	258.6
Recertification	5660.8	7926.1	13586.9
Fee	780.1	1035.4	1815.5
Program Office Management	538.2	718.0	1256.2
Total Operations	9507.8	12684.7	22192.5

Table A-141
Operational Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 2.5 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (57 Launches)			
Launch Operations	29.6	42.1	71.7
Propellants	(3.1)	(20.1)	(23.2)
Launch Area Support	12.3	14.5	26.8
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	2.3	3.0	5.3
Recovery	7.6	7.6	15.2
Transportation	.2	.2	.4
Tech Support & Sustaining Engr	11.7	15.6	27.3
Sustaining Spares	9.0	17.7	26.7
Recertification	4.7	7.0	11.7
Fee	7.1	8.4	15.6
Program Office Management	5.3	7.2	12.5
Total Operations	93.7	127.2	220.9
Intermediate (57 Launches)			
Launch Operations	47.2	61.6	108.8
Propellants	(3.1)	(20.1)	(23.2)
Launch Area Support	45.4	53.7	99.1
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	5.1	6.6	11.7
Recovery	14.8	14.8	29.6
Transportation	8.3	8.4	16.7
Tech Support & Sustaining Engr	14.0	18.7	32.7
Sustaining Spares	15.1	29.5	44.6
Recertification	220.4	396.9	617.3
Fee	35.1	55.4	90.5
Program Office Management	24.7	39.1	63.8
Total Operations	436.9	691.6	1128.8
Current (59 Launches)			
Launch Operations	123.8	127.7	251.5
Propellants	(3.2)	(20.9)	(24.1)
Launch Area Support	124.2	147.4	271.6
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	11.8	15.3	27.1
Recovery	15.3	15.3	30.6
Transportation	9.0	9.5	18.5
Tech Support & Sustaining Engr	19.5	26.0	45.5
Sustaining Spares	29.0	54.7	83.7
Recertification	464.2	801.7	1265.9
Fee	78.3	116.5	194.8
Program Office Management	53.3	79.6	132.9
Total Operations	941.8	1407.1	2348.9

Table A-142
Operational Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 8 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (181 Launches)			
Launch Operations	76.9	131.6	208.5
Propellants	(9.7)	(64.0)	(73.7)
Launch Area Support	20.7	25.8	46.5
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	3.8	4.8	8.6
Recovery	18.0	18.0	36.0
Transportation	.3	.3	.6
Tech Support & Sustaining Engr	11.7	15.6	27.3
Sustaining Spares	16.6	31.4	48.0
Recertification	52.5	91.9	144.4
Fee	17.6	24.1	41.7
Program Office Management	13.3	20.9	34.2
Total Operations	235.5	368.6	604.1
Intermediate (182 Launches)			
Launch Operations	127.1	192.5	319.6
Propellants	(9.7)	(64.3)	(74.0)
Launch Area Support	76.7	95.9	172.6
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	8.4	10.5	18.9
Recovery	35.8	35.8	71.6
Transportation	26.2	26.4	52.6
Tech Support & Sustaining Engr	14.0	18.7	32.7
Sustaining Spares	28.0	52.7	80.7
Recertification	698.8	1277.8	1976.6
Fee	95.0	159.1	254.1
Program Office Management	67.0	112.6	179.6
Total Operations	1183.9	1988.8	3172.7
Current (185 Launches)			
Launch Operations	317.2	387.4	704.6
Propellants	(9.9)	(65.4)	(75.3)
Launch Area Support	209.2	261.6	470.8
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	19.2	24.0	43.2
Recovery	36.4	36.4	72.8
Transportation	28.0	29.6	57.6
Tech Support & Sustaining Engr	19.5	26.0	45.5
Sustaining Spares	53.5	97.4	150.9
Recertification	1315.5	2237.0	3552.5
Fee	193.8	298.1	491.9
Program Office Management	132.3	204.7	337.0
Total Operations	2337.9	3615.7	5953.6

Table A-143
Operational Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 15 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (339 Launches)			
Launch Operations	133.2	244.7	377.9
Propellants	(18.2)	(119.8)	(138.0)
Launch Area Support	29.1	37.1	66.2
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	4.7	5.8	10.5
Recovery	31.2	31.2	62.4
Transportation	.5	.5	1.0
Tech Support & Sustaining Engr	11.7	15.6	27.3
Sustaining Spares	22.0	41.0	63.0
Recertification	132.0	236.2	368.2
Fee	31.9	46.5	78.4
Program Office Management	24.0	39.8	63.8
Total Operations	424.3	702.3	1126.6
Intermediate (342 Launches)			
Launch Operations	224.1	358.2	582.3
Propellants	(18.3)	(120.9)	(139.2)
Launch Area Support	108.2	137.9	246.1
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	10.4	12.9	23.3
Recovery	62.7	62.7	125.4
Transportation	49.1	49.7	98.8
Tech Support & Sustaining Engr	14.0	18.7	32.7
Sustaining Spares	37.0	68.7	105.7
Recertification	1284.3	2348.7	3633.0
Fee	166.7	283.1	449.8
Program Office Management	117.8	200.9	318.7
Total Operations	2081.3	3548.4	5629.7
Current (346 Launches)			
Launch Operations	548.8	715.1	1263.9
Propellants	(18.5)	(122.3)	(140.8)
Launch Area Support	294.3	375.5	669.8
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	23.9	29.5	53.4
Recovery	63.5	63.5	127.0
Transportation	52.2	55.2	107.4
Tech Support & Sustaining Engr	19.5	26.0	45.5
Sustaining Spares	70.9	127.8	198.7
Recertification	2283.2	3876.9	6160.1
Fee	323.5	504.2	827.7
Program Office Management	221.6	347.2	568.8
Total Operations	3914.8	6134.2	10049.0

Table A-144
Operational Phase Cost Summary
(Millions of 1969 Dollars)
45 K Concept "M", 25 M LB Total Payload Delivered, 10 Years

	ORBITER	BOOSTER	TOTAL
ILRV (564 Launches)			
Launch Operations	210.6	404.6	615.2
Propellants	(30.2)	(199.3)	(229.5)
Launch Area Support	39.2	50.6	89.8
Training & Mission Support	4.0	4.0	8.0
Age & Facility Maintenance	5.5	6.8	12.3
Recovery	50.1	50.1	100.2
Transportation	.6	.6	1.2
Tech Support & Sustaining Engr	11.7	15.6	27.3
Sustaining Spares	27.1	50.0	77.1
Recertification	218.7	391.9	610.6
Fee	48.7	72.4	121.1
Program Office Management	37.0	62.8	99.8
Total Operations	653.2	1109.5	1762.7
Intermediate (570 Launches)			
Launch Operations	358.4	592.7	951.1
Propellants	(30.5)	(201.4)	(231.9)
Launch Area Support	145.9	188.4	334.3
Training & Mission Support	6.8	6.8	13.6
Age & Facility Maintenance	12.2	15.0	27.2
Recovery	101.0	101.0	202.0
Transportation	81.8	82.8	164.6
Tech Support & Sustaining Engr	14.0	18.7	32.7
Sustaining Spares	45.7	83.9	129.6
Recertification	2086.6	3868.8	5955.4
Fee	263.9	457.3	721.2
Program Office Management	187.0	324.9	511.9
Total Operations	3303.4	5740.3	9043.7
Current (575 Launches)			
Launch Operations	867.9	1177.8	2054.7
Propellants	(30.8)	(203.2)	(234.0)
Launch Area Support	396.5	511.9	908.4
Training & Mission Support	13.3	13.3	26.6
Age & Facility Maintenance	27.9	34.2	62.1
Recovery	102.0	102.0	204.0
Transportation	86.7	91.7	178.4
Tech Support & Sustaining Engr	19.5	26.0	45.5
Sustaining Spares	87.5	156.5	244.0
Recertification	3546.4	6016.9	9563.3
Fee	492.8	773.4	1266.2
Program Office Management	338.4	534.2	872.6
Total Operations	5979.0	9437.9	15416.9